HANDS-ON EXPERIENCE IN THE BEAM DIAGNOSTICS: STRIPLINE BPM AND SR INTERFEROMETER *

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Abstract

In today's particle accelerators, precise beam diagnostics are essential because the beam travels invisibly through vacuum chambers, and direct access is impossible during operation. Diagnostics, often referred to as the "eyes and ears" of accelerators, are required to monitor key beam properties such as position, size, and stability in real time. Among these, the beam position monitor (BPM) is crucial for tracking the transverse position of the beam bunch and enabling stable control. This experiment focused on a stripline BPM, which detects beam-induced electromagnetic signals via electrodes embedded in the vacuum chamber. A wire simulating the beam was moved by a translation stage, and the BPM response was analyzed to evaluate its performance. Additionally, the synchrotron radiation (SR) interferometer was studied as a non-destructive optical device to measure the beam size based on interference patterns formed by beam radiation. These systems illustrate the fundamental techniques used to observe and control the beam in the accelerator.

INTRODUCTION

In a particle accelerator, the beam travels through a vacuum chamber and is completely invisible to the naked eye during operation. Furthermore, due to radiation hazards and strict safety protocols, it is impossible to physically approach the accelerator while the beam is on. Therefore, accelerators must be equipped with reliable monitoring systems that can measure key beam parameters—such as position, size, and stability—in real time and without direct access. These diagnostic tools serve as the "eyes and ears" of the accelerator, enabling scientists and engineers to ensure stable and optimized beam delivery. In this context, beam position monitors (BPMs) play a critical role in tracking the transverse location of the beam along the beamline.

In this experiment, we focused on the performance and position accuracy evaluation of a stripline-type BPM, which detects beam-induced signals on electrode structures embedded in the vacuum chamber. The wire for beam position measurement was moved along a specific path by a motor and we checked that it moved accurately to the input position. Additionally, we studied the principle and application of a synchrotron radiation (SR) interferometer, which measures the transverse beam size based on interference patterns formed by passing light through double slits. The optical equipment was set up until an interference pattern appeared by combining various types of slits, and this was recorded with a streak camera to obtain an image.

These two diagnostic systems together offer complementary information essential for high-precision beam control in modern accelerators. By understanding and operating these diagnostic instruments, we gain essential insight into how a beam bunch is monitored and controlled in real accelerator environments. This knowledge forms the foundation for future work in beam physics and engineering like accelerator tuning and design, and high-precision experiments which require beam stability.

BEAM PROFILE MONITOR THEORY

Stripline Beam Position Monitor

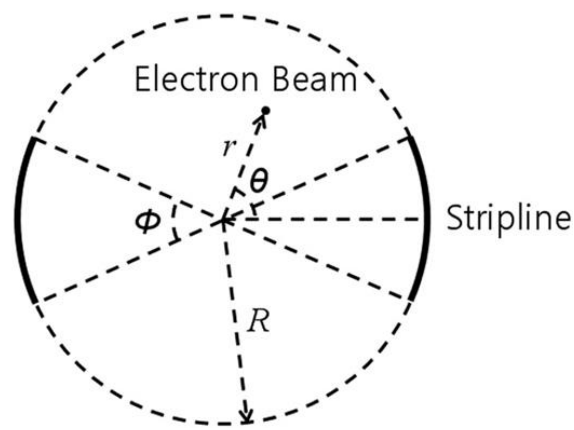

Figure 1: A transverse drawing of a typical stripline BPM.

A stripline BPM is a non-destructive diagnostic device used to measure the transverse position of a charged particle beam inside an accelerator's vacuum chamber. It consists of symmetrically placed stripline electrodes that couple electromagnetically to the beam as it passes through. As the relativistic beam induces image currents on the electrodes, the signals generated on each stripline are dependent on the beam's proximity to that electrode. By measuring the difference in signal amplitudes from opposing striplines (e.g., left vs. right, top vs. bottom), the transverse beam position can be determined by difference-over-sum ratio as follows:

$$\frac{\Delta}{\Sigma} = \frac{V_r - V_l}{V_r + V_l} = \frac{2\sin(\phi/2)}{\phi/2}\frac{x}{R} \quad (1)$$

where V_r and V_l are measured voltages from the right and the left stripline, respectively. R is the vacuum chamber radius, and ϕ is the stripline angular width. We can see the cross-sectional structure of the apparatus in Fig. 1. The induced charges on the right and the left stripline are measured and we can figure out the transverse position of a beam bunch inside the chamber [1].

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SR Interferometer

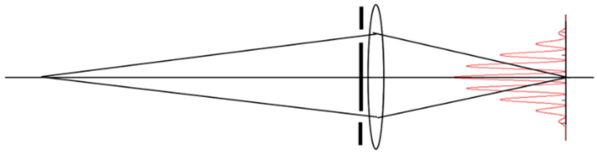


Figure 2: A simple representation of the visibility of an interferogram and light source size [2].

A SR interferometer is a high-precision optical system used to measure the transverse size (beam width) of a particle beam by analyzing the interference pattern of the synchrotron radiation emitted from the beam. When high-energy electrons are bent by a magnetic field in a storage ring, they emit synchrotron radiation tangentially. This light passes through a double-slit (Young's slit) setup, and the resulting interference pattern captured by a streak camera is observed on a screen or detector.

According to van Citterut-Zernike's theorem, which relates the spatial coherence of light to the source distribution, the beam size can then be extracted by fitting the fringe pattern using known slit geometry and wavelength. Assume f is the beam profile as a function of position y, and R is the distance between source beam and the double slit, and γ denotes the complex degree of spatial coherence as a function of spatial frequency υ . Then the spatial coherence is treated by the Fourier transform of f as follows:

$$\gamma(v) = \int f(y) \exp(-2\pi i v \cdot y) dy, \quad v = \frac{2\pi \mathrm{D}}{\lambda R} \tag{2}$$

It indicates that the beam profile and the beam size can be measured by spatial coherence [3].

The streak camera shoots an image via the pinhole and it defines the visibility via the intensity of the interferogram, I, like below equation:

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \tag{3}$$

After obtaining V, the distance between the source point and the pinholes, L, the beam size is computed as:

$$\sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{V}} \tag{4}$$

where λ is the radiation wavelength and D is the distance between pinholes which is also applied to Eq. (2). In real experiment, we have to measure all the parameters and calibrate the optical tools ranging from the streak camera to the slits. Through this, we can calculate the beam size with interference pattern profile [4].

EXPERIMENTAL SETUP

Confiruation of the Wire Test Stand

The wire test stand is composed of a wire-supporting frame, a trigger generator, a signal generator, a two-dimensional translation stage, a motor controller, BPM electronics, and a data acquisition computer. A continuous 500 MHz signal is fed from the signal generator into a 0.5mm diameter wire, which passes through the BPM pickup. The BPM pickup can be translated horizontally and vertically using the two-axis stage, whose position is monitored by dual encoders with 1μm resolution. Movement of the stage is managed by a logic controller (PLC), which communicates with the computer via a serial interface. The BPM electronics enable precise measurement of the relative position of the wire with respect to the center of the BPM.

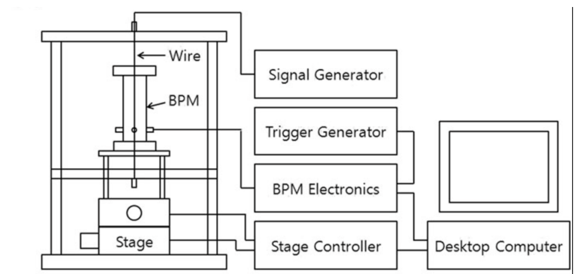


Figure 3: The wire test stand for the position sensitivity and the offset measurement in a nutshell [1].

SR Interferometer in Synchrotron

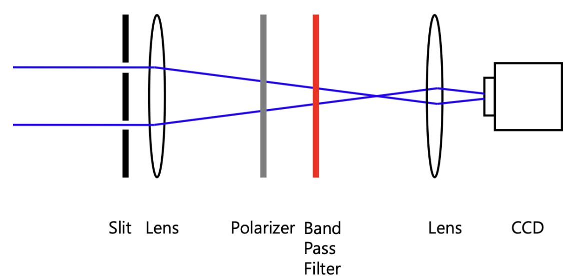


Figure 4: A schematic layout of the SR interferometer apparatus.

This experiment is conducted at the Pohang Light Source II (PLS-II) beamline to monitor the sychrotron radiation light. The light is collimated by four kinds of slit sizes which comprise four pinholes and form the interference patterns. The main parameters are the slit width and the distance between the two slits, which were varied to analyze their effects on the interference pattern. The slit width influences both the overall intensity and the size of the image; a narrower slit improves the resolution but reduces light intensity. The distance between the slits determines the interference spacing, as it is directly related to the distance between the local maxima and minima in the interference pattern.

RESULT AND ANALYSIS

Wire Test Stand Performance

A horizontal translation stage is moved in the cross-diagonal direction via an encoder, as shown in Fig. 5. There are three dominant factors that affect the measurement results: Position accuracy which indicates the degree to which the motor's input value matches the actual value; straightness which indicates whether it moves in a straight line without abberation; and repeatability, which indicates whether it can return to its original position after the motion. The measurement is conducted in the range of ±6,000μm in each axis. At the origin, the repeatability of returning to the original position was proven within 1μm, which is the resolution of the motor. In terms of linearity, it was confirmed that it deviates within a range of up to 500μm at a point of about ±3mm on the axis. This means that the position can be accurately measured in the center of the BPM device, i.e. where the beam passes.

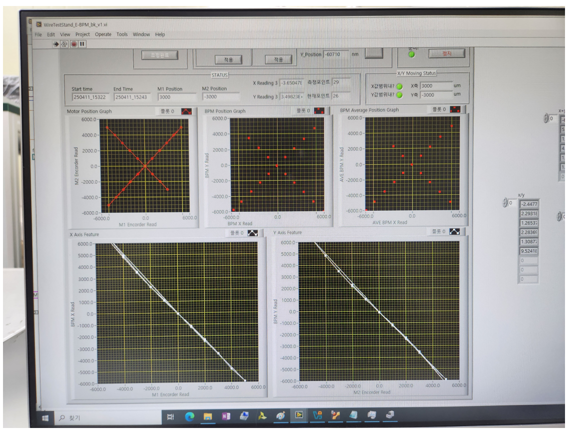


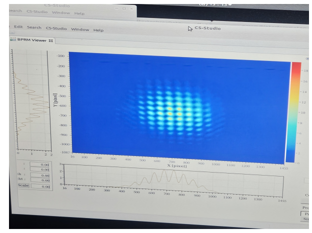
Figure 5: A position control system of the translation stage displayed on the data acquisition computer.

Interference Pattern Acquisition

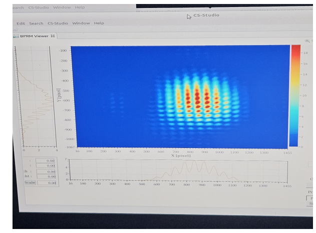
In the SR interferometer experiment, we observed that the horizontal interference patterns were clearly separated compared to the vertical one. The vertical patterns were densely packed and barely distinguishable almost like a continuous line, especially in the central area. This difference is primarily attributed to the intrinsic asymmetry in the beam dimensions; the vertical beam size is significantly smaller than the horizontal beam size. According to the van Cittert–Zernike theorem, smaller beam sizes result in wider pattern spacing, while larger beam sizes lead to narrower spacing due to reduced spatial coherence. Therefore, densely packed vertical patterns indicate a larger effective beam size in that direction or increased sensitivity to vibrations. This explains why the vertical patterns are compressed or blurred, while the horizontal pattern remains more distinct and measurable [4].

CONCLUSION

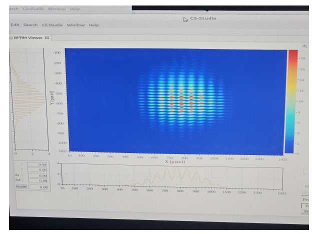
Through this experiment, we gained hands-on experience with two core diagnostic systems used in particle accelerators: the stripline BPM and the SR interferometer. In the BPM test, a wire driven by a precision translation stage was used to simulate the position of the beam, allowing us to evaluate the accuracy of the equipment, such as linearity and repeatability. The results showed accurate and reliable position alignment near the BPM center, confirming the effectiveness of the system in real beamline applications. The SR interferometer experiment revealed how slit width and separation affect interference visibility, and how beam size can be extracted using the interference pattern analysis based on the van Cittert–Zernike theorem. Notably, the horizontal interference patterns were clearly distinguishable, whereas the vertical ones were compressed due to the smaller vertical beam size and optical limitations. This highlighted the asymmetry in beam dimensions and the importance of optical alignment in measurement precision. Collectively, the experiment demonstrated how beam position and size monitoring work together to ensure high-quality beam control.



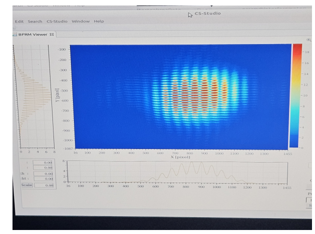
(a) 15x18 mm



(b) 15x22 mm



(c) 15x35 mm



(d) 15x40 mm

Figure 6: Interference pattern observed in the beamline depending on the size of double slits.

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