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DEVELOPMENT OF WHITE BEAM PROFILE MONITOR FOR KOREA-4GSR

W. Song, M. Chung,* Pohang University of Science and Technology, Pohang, Korea
S. Kim, H. Hyun, S. Hwang, S. Lee, M. Kim, Y. Park, J. Lim, G. Hahn
Pohang Accelerator Laboratory, POSTECH, Pohang, Korea

Abstract

Accurate measurement of photon beam position and profile is crucial for beamline users to achieve precise alignment and efficient utilization of the desired photon beam. In low-emittance storage rings, however, the power density of the photon beam has increased, making it challenging for conventional profile monitors such as wire scanners and scintillating screens to withstand the high power without damage. Here, we present the development of a White Beam Profile Monitor (WBPM) capable of robustly measuring the photon beam position and enabling non-destructive beam profile measurement. The WBPM, consisting of two chambers, was designed to enable simultaneous measurements of horizontal and vertical beam profiles. Its performance was evaluated at the PLS-II wiggler beamline, where results were compared against those from a screen monitor. The photon beam profile, sharply defined by a slit, was successfully measured in both directions, and the point spread function was estimated to be approximately 120 µm. Furthermore, vertical position measurements demonstrated a position resolution of 30 µm at an exposure time of 0.3 ms, confirming the feasibility of the WBPM for photon beam diagnostics.

INTRODUCTION

In diffraction-limited storage rings (DLSRs), the electron beam emittance is reduced by nearly two orders of magnitude compared to third-generation facilities. This reduction leads to a smaller photon beam size and divergence approaching the diffraction limit. At Korea-4GSR, the concentrated beam reaches power densities up to ten times higher than those of existing sources. For beamline operation, photon beam profile measurements are required to identify the central cone of undulator radiation. However, conventional diagnostics such as wire scanners and fluorescent screens face severe thermal challenges under high-power white beam conditions. This necessitates the development of alternative non-invasive methods.

An ionization profile monitor (IPM) is a non-destructive diagnostic device, unlike conventional monitors. Because the IPM does not directly intercept the beam, it avoids damage and enables continuous, real-time monitoring. The principle relies on the ionization of residual gas within the vacuum chamber by charged particles or photon beams. The resulting ion–electron pairs are extracted before recombination and accelerated in opposite directions under an applied electric field. As the ions reach the readout, their spatial distribution is converted into an electrical signal or image. In this way, regions of higher beam density produce stronger signals, allowing the transverse intensity distribution of the beam to be reconstructed.

IPMs are already widely used in synchrotrons [1–3], and more recently have been developed for photon beam diagnostics [4–6]. To measure the white-beam profile in insertion device (ID) beamlines, we are developing a White Beam Profile Monitor (WBPM). Particular emphasis has been placed on analyzing the Point Spread Function (PSF) to ensure sufficient spatial resolution. In this paper, we present the results from installing the WBPM at the PLS-II beamline, where synchrotron radiation was directly measured to evaluate the beam profile and position.

WHITE PHOTON BEAM PROFILE MONITOR

As shown in Fig. 1, the WBPM consists of guiding electrodes for ion extraction, and a readout assembly composed of a Microchannel Plate (MCP) and a shield plate [7]. Each electrode and the MCP are biased individually through dedicated high-voltage feedthroughs. The MCP used was Hamamatsu's F2223-21P model. It consists of a 2-stage chevron-type channel and features a phosphor screen at the exit. The overall configuration of the WBPM is shown in Fig. 2. It consists of a horizontal chamber on the left, a central chamber for gas injection and pumping, and a vertical chamber on the right. The beam distribution obtained from the MCP is measured as an image through a window using an externally mounted CMOS camera (Manta G-235b). Xenon gas is injected into the central chamber using a mass flow controller to maintain a constant pressure, and a residual gas analyzer is installed to measure the residual gas and xenon gas composition environment.

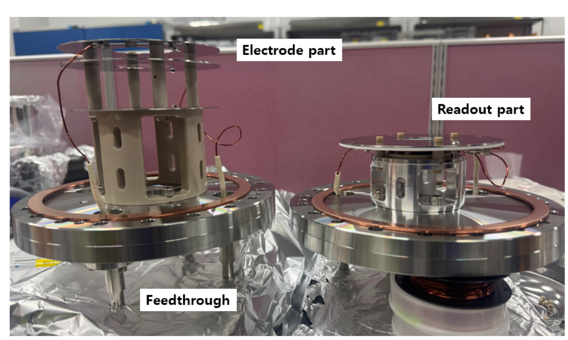

Figure 1: Assembly of the WBPM readout and electrodes.

* moses@postech.ac.kr

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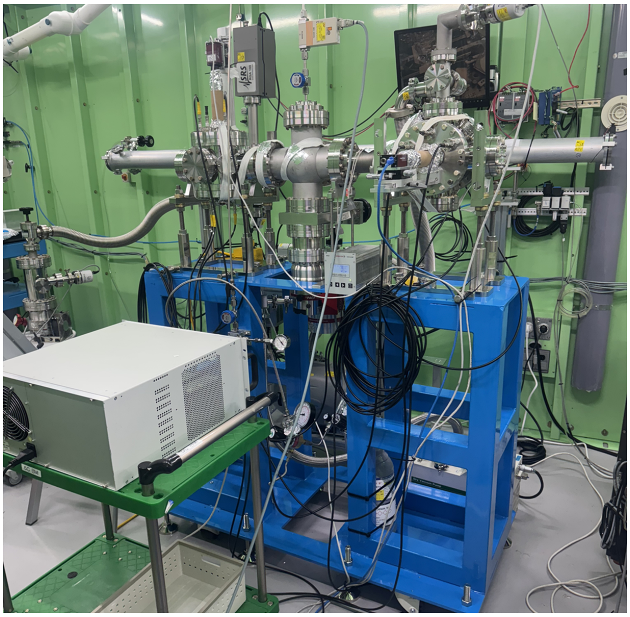

Figure 2: WBPM installed on the beamline.

Set-up

The WBPM prototype test was conducted at the 6C Biomedical Imaging beamline of the Pohang Light Source-II. Here, white beams above 10 keV can be imaged, making it suitable for profile measurements. The photon beam from the multipole wiggler passes through a 1.4 mm thickness diamond window and a 0.1 mm thickness Al window. After passing through the diamond window, the beam is reflected by the Double Multilayer Monochromator (DMM) and then guided through a slit. The WBPM is installed downstream of the slit inside the experimental hutch, positioned just in front of the screen monitor.

As the beam passes through windows, photons with energies below 20 keV are largely attenuated, allowing only the hard X-ray component to reach the end station. Ionization events are primarily induced by the photoelectric effect, whose cross-section decreases significantly with increasing photon energy. Consequently, the number of ionization events is extremely limited in the hard X-ray regime, especially within residual gas, making the WBPM unsuitable for use in this region. To overcome this limitation, we utilized xenon gas, as its high atomic mass substantially enhances the cross-section, thereby providing a sufficient number of ionization events.

RESULTS

Beam Profile Measurement

Photon beam profiles were measured by partially blocking the beam with a slit, producing the distribution shown in Fig. 3. The corresponding images obtained with the screen monitor and the WBPM in the horizontal and vertical directions are presented in Fig. 3 (right) and Fig. 4 (top and bottom), respectively. The WBPM images were acquired with a 75 seconds camera exposure, and background images recorded without Xe gas were subtracted. In both axes, the WBPM images clearly revealed the beam density distribution along the beam path. In the horizontal monitor, however, the distribution appeared as a curved band centered on the beam axis. This led to a discrepancy with the screen monitor of nearly 2 mm in the horizontal profile (Fig. 5). The results from both monitors showed good overall agreement, and the difference in the vertical profile FWHM between the WBPM and the screen monitor was within 20 µm.

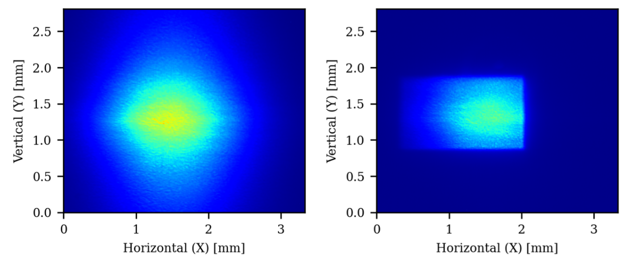

Figure 3: Transverse X-ray profiles measured by the screen monitor with the slit fully open (left) and partially closed (right).

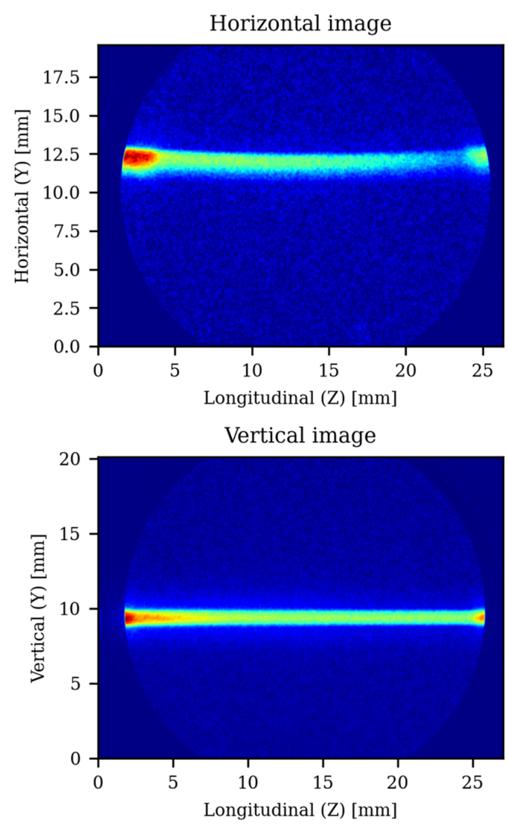

Figure 4: Horizontal and vertical images measured by the WBPM.

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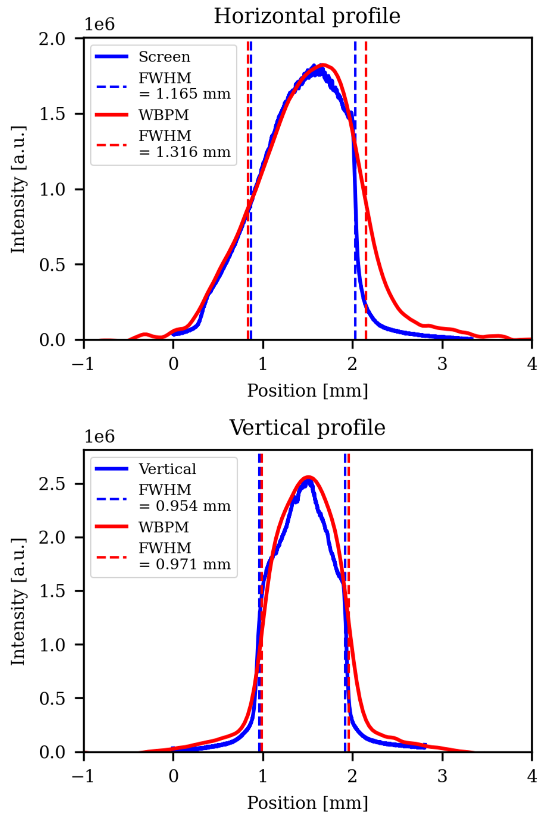

Figure 5: Beam profiles obtained by projecting images from the WBPM and the screen monitor.

Beam Position Measurement

The vertical beam position was varied by adjusting the pinch of the DMM. For the displacement test, the WBPM camera exposure time was set to 0.3 seconds, and the corresponding image is shown in Fig. 6. Background subtraction was applied; however, due to the short exposure time, the random noise was not eliminated. The DMM angle was varied in seven steps, and for each position, 600 WBPM images were recorded. The relationship between the beam center positions measured by the screen monitor and the WBPM is shown in Fig. 7. The position resolution was determined from the deviation of the 600 image centers and the fitting error, yielding a value of 29.37 µm.

CONCLUSION

A WBPM was developed for monitoring the profile and position of high-power white beams in DLSRs, and its performance was tested at the PLS-II ID beamline. The results showed good agreement between the photon beam profiles measured by the fluorescent screen and the WBPM, where a slit shaped the beam. The beam size difference was within 20 µm in the vertical profile, and the position measurement resolution was measured to be 29.37 µm. In the PLS-II experiment, most of the soft X-ray region where ionization reactions occur was removed by the diamond and Al windows, so Xe gas was injected to increase the reaction rate.

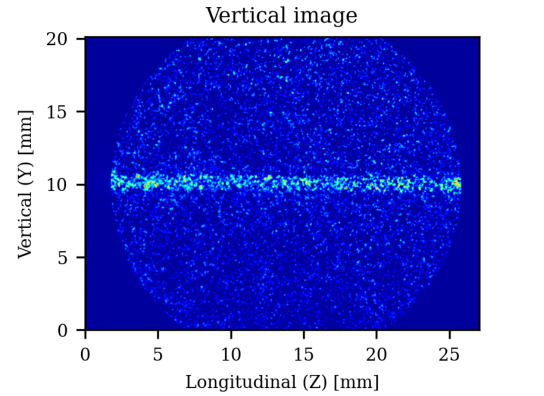

Figure 6: WBPM image measured with an exposure time of 0.3 seconds.

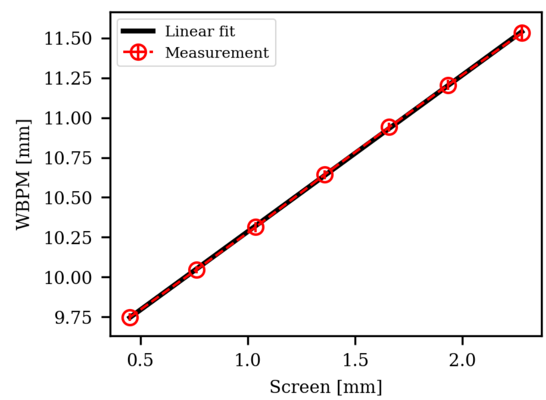

Figure 7: Comparison of position measurements between the screen monitor and WBPM for varying beam positions.

Further WBPM development is underway to measure the white beam using residual gas in front of the DMM or DCM for Korea-4GSR.

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