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# DESIGN OF X-RAY IONIZATION BEAM PROFILE MONITOR FOR KOREA-4GSR

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*Abstract*

A photon beam generated by the Insertion Device (ID) of a synchrotron light source can be contaminated by radiation from upstream and downstream bending magnets, leading to position measurement errors in blade-type monitors. The operation of the Korea-4GSR, which has an extremely low emittance, is particularly sensitive to photon beam position variations, necessitating more accurate position measurements. To robustly measure the position and simultaneously obtain the profile of a photon beam in a non-destructive manner, we are developing an ionization profile monitor.

We designed a noble gas environment to ensure adequate signal strength and incorporated a defocusing electrode structure to fully utilize the relatively large active area of the readout. Since magnification in the defocusing field depends on the vertical position, we proposed a calibration method to correct the non-linearity, which we then verified through particle tracking simulation.

## INTRODUCTION

The Ionization Profile Monitor (IPM) is used in many synchrotrons [1–5] to monitor the profile and position of the beam. As shown in Fig. 1, the beam ionizes the residual gas by the photoelectric effect, and the resultant ions or electrons are collected to measure the beam information. Diagnostics using ionization have the advantage of being non-destructive, as the beam is not blocked and only a small fraction of the beam participates in the reaction.

At the ID beamline of the synchrotron light source, the X-ray from the undulator as well as light from the upstream and downstream bending magnets arrive at the same time [6]. The center of this X-ray is measured using a blade-type Photon Beam Position Monitor (PBPM), which uses the edge information of the beam to determine the position to avoid heating. In this case, contamination can affect the position measurement and cause errors. IPM is free from this problem because it measures the entire intensity distribution without using a part of the beam so that it can overcome errors caused by contamination.

IPM with its many benefits has already been studied in PETRA-III [7], FLASH [8], etc, for X-ray beam position monitoring. Higher spatial resolution is required for precise measurement of position, especially profile, in low emittance storage rings such as Korea-4GSR. Therefore, this study shows the IPM design for resolution improvement and the calibration method for precise profile and position measurement.

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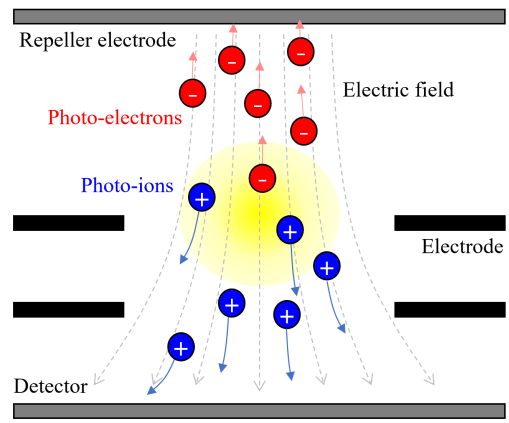


Figure 1: Schematic diagram of IPM.

## IONIZATION PROFILE MONITOR DESIGN

The major components that determine the resolution of IPM are extraction field quality, transverse growth of photo-ion, readout device resolution, and data processing. Non-uniformity of the electric field induced by fabrication tolerance or errors in the applied voltage creates measurement errors. In addition, the thermal energy and space charge of the initial photo-ion have the effect of increasing the point spread function due to transverse spread during the drift of the ion. The optical readout using the MCP produces errors of more than 100 μm due to the channel pitch of the MCP, the chevron structure, the phosphor, and the camera resolution. In addition, errors in image processing also contribute to the resolution of the IPM.

Our IPM design intends to use a noble gas (Xenon) with a large ionization cross-section instead of a residual gas to increase the signal gain and the signal-to-noise ratio. Furthermore, the transmission ratio of ions was improved by removing the grid mesh for sustaining field uniformity. In this process, a shield plate was installed on the MCP to ensure the uniformity and isotropy of the extraction field, and the electrode and repeller structures were also optimized. The design of the extraction field is 1:1 mapping to increase the resolution by utilizing the active area of the MCP, which is relatively large compared to the beam. The measurement result changes depending on the initial ion generation position in the defocusing field, which causes profile and position measurement errors. The error was corrected by the magni-

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fication correction method and verified by particle tracking simulation.

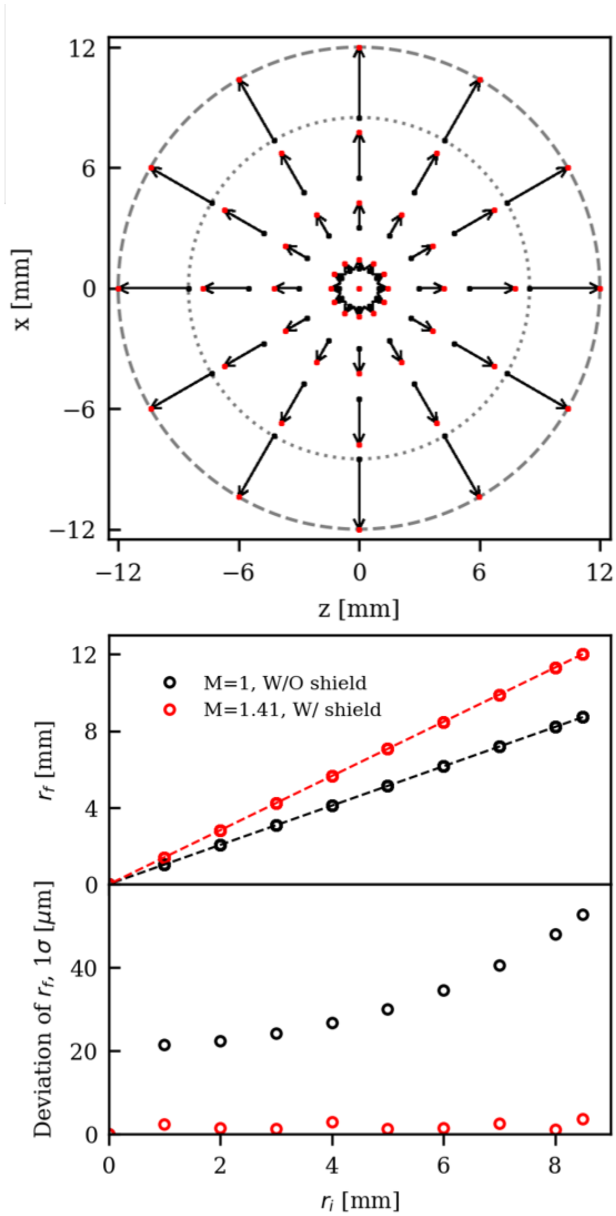


Figure 2: (top) Ions are generated in black dots and arrive at red dots along the designed electric field; (bottom) The ratio (magnification) of the arrival position $r_f$ to the departure position $r_i$ is designed to be 1.41, and the arrival position distribution is reduced to within 6 μm by installing a shield plate.

The dominant component that determines the resolution of the IPM is the resolution of the readout, including the MCP. This is structurally difficult to overcome, so we intend to improve the resolution by magnifying the measurement image. As shown in Fig. 2, the ions arrive at the MCP with a constant ratio to the distance from the initial center, so that the distribution of the beam is broadened. We designed a defocusing field that maps 1:1 between where the ions are generated and where they arrive at the MCP, as shown in the equipotential lines in Fig. 3 (a) so that the magnified distribution can be obtained without image distortion. The distance from the center is measured to be 1.41 times larger, considering the expected source and the active area of the MCP.

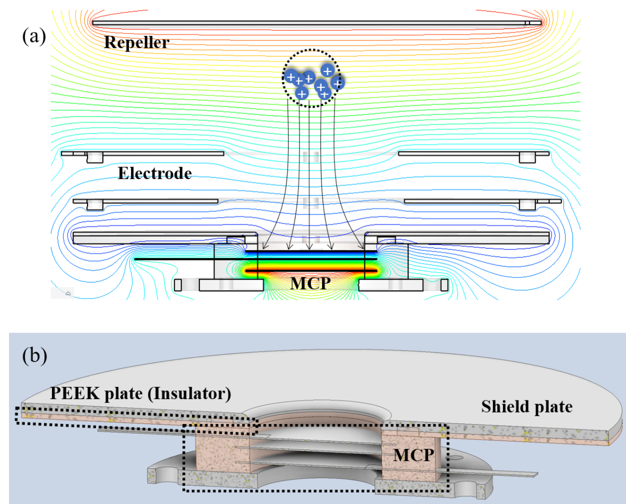


Figure 3: (a) Equipotential lines calculated by CST. Here, ions broaden along a spreading electric field. (b) Shield plate design.

The removal of the mesh grid to increase the ion transmission ratio is a factor that worsens the uniformity of the field. If the extraction field is not sufficiently isotropic, however, it will generate more distortion in the profile measurement, so electrode optimization is required to achieve an isotropic field. Both the electrode and MCP are cylindrical structures, so there is no problem with isotropy. The asymmetrical structure of the leads, however, creates an an-isotropic field in the ion drift region. In particular, the MCP lead bar has high voltages applied in different directions, which cannot be optimized by adjusting the dimensions of the electrodes and the applied voltage. To minimize the effect of voltage on the leads, a shield plate, shown in Fig. 3 (b), is designed on the top of the MCP and a PEEK plate to prevent discharge. The shield plate improved the linearity, as the particle tracking simulation showed that the shield plate installation reduced the distribution of ion arrival locations to 10 % as shown in Fig. 2.

## POSITION CALIBRATION: MAGNIFICATION CORRECTION METHOD

The 1:1 mapping field is a defocusing field structure to magnify a relatively small source. This structure can cause distortion of the 2D intensity distribution information due to lens effects. If the magnification is constant, there is no difficulty in estimating the original signal from the arrival position of the ions. However, if the vertical position is different, the magnification changes. This leads to errors in

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the profile measurement as well as the center position of the beam. Therefore, a calibration method that compensates for the distortion is required to correct this error.

Through electrode optimization, we designed an isotropic field, which means that ions generated in the same horizontal plane all have the same magnification. Therefore, in one horizontal plane, the generation and arrival positions of photo-ions correspond without overlapping. If we also consider the vertical position, we can expect a collection of ion generation positions (dashed line in Fig. 4) corresponding to an arbitrary arrival position (position measured in the readout). On the other hand, in general, IPMs are used in pairs for both horizontal and vertical axis measurements. Then another set of expected positions (dotted line in Fig. 4) can be obtained from the vertical monitor. As a result, the actual ion generation location can be guessed from the intersection of the two monitors' estimated locations. The specific correction method is explained in Fig. 4

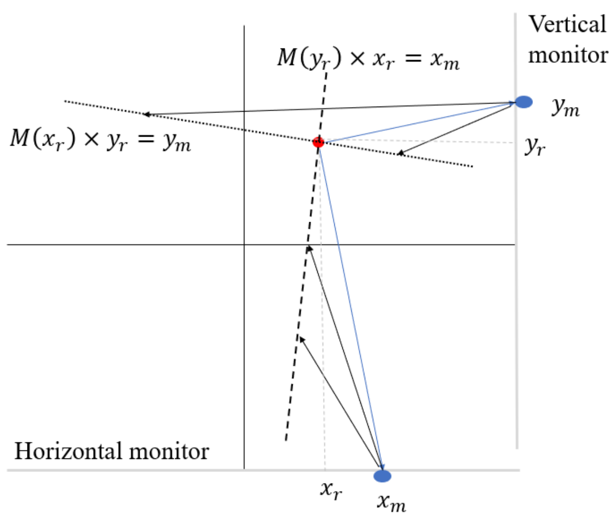


Figure 4: Magnification correction process. First, the magnification function $M$ for calibration is obtained by scanning the source position in the transverse plane. The positions $x_m$, and $y_m$ of the beam measured during actual IPM operation are already the result of the real position multiplied by $M$. Therefore, the actual positions $x_r$, and $y_r$ can be obtained by calculating $x_m$, $y_m$, and $M$ measured by each monitor. Finally, the image of each monitor is deconvolved with the $M$ found earlier to reconstruct the original profile.

To validate the calibration method, we simulated the measurement results by tracking ions in the electric field of the designed IPM. The magnification is calculated linearly according to the vertical offset, and the result can be seen in Fig. 5. We calculated the error of the magnification correction method using the expected distribution of the beam at the Korea-4GSR IVU20 beamline, and the result is shown in Fig. 6. The horizontal offset is 3 mm, and the calculation error is within 40 µm when the vertical offset is changed, which is sufficiently applicable considering the resolution of the detection system. However, calibration errors can change depending on the electric field quality, so we need to verify the calibration method by measuring the calibration map experimentally.

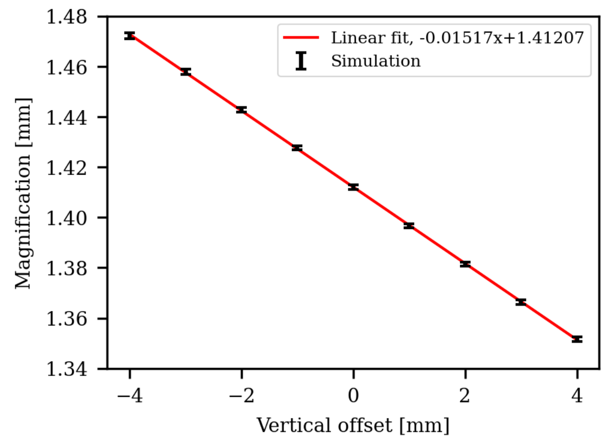


Figure 5: A magnification function $M$ for the vertical position obtained by simulation.

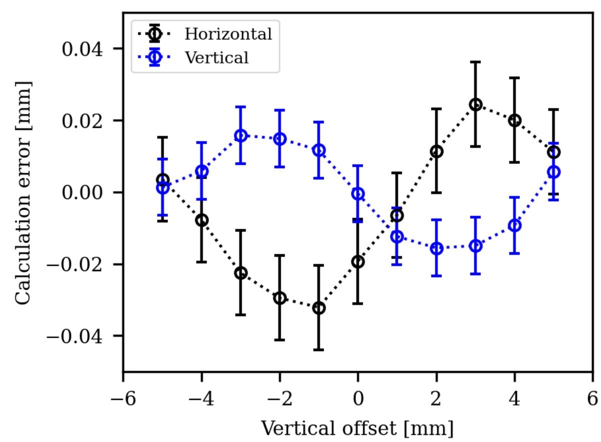


Figure 6: Simulation results of position measurement error caused by vertical offset.

## CONCLUSION

We designed an IPM for X-ray measurements and proposed a calibration method. The new proposed design for the Korea-4GSR is being developed to be applied to the PLS-II and will be experimentally validated on the PLS-II.

## ACKNOWLEDGMENTS

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