Compact integrated X-ray intensity and beam position monitor based on rare gas scintillation

Peter Revesz, Jacob Ruff, Darren Dale, and Thomas Krawczyk
 Cornell University, Cornell High Energy Synchrotron Source, Ithaca, New York 14853, USA

(Received 8 April 2013; accepted 10 May 2013; published online 24 May 2013)

We have created and tested a compact integrated X-ray beam intensity and position monitor using Ar-gas scintillation. The light generated inside the device's cavity is detected by diametrically opposed PIN diodes located above and below the beam. The intensity is derived from the sum of the top and bottom signals, while the beam position is calculated from the difference-over-sum of the two signals. The device was tested at Cornell High Energy Synchrotron Source with both 17 keV and 59 keV x-rays. For intensity monitoring, the Ar-scintillation monitor performance is comparable to standard ion chambers in terms of precision. As an X-ray beam position monitor the new device response is linear with vertical beam position over a 2 mm span with a precision of 2 μm . © 2013 AIP Publishing LLC. [<http://dx.doi.org/10.1063/1.4807698>]

I. INTRODUCTION

There are a number of ways to monitor X-ray beam intensity and position at synchrotron light source experimental stations. Ion chambers are widely used to monitor X-ray intensity (defined in units of photons/s) in an unobtrusive way. X-ray scattering from thin films is also used to measure intensity in an unobtrusive way. Silfhout *et al.*^{1–6} have enhanced scattering-based intensity monitoring by imaging the X-ray footprint using arrays of Soller slits or pinholes in combination with a PIN diode array or CCD imaging device. Most relevant to the work reported here, Suzuki *et al.*⁹ have developed a high intensity X-ray monitor based upon the scintillation of the Ar gas. They have shown that Ar-scintillation monitors offer several advantages over the traditional ion chambers. Scintillation appears to be unaffected by space charge effects, as the device response is linear for high intensity x-ray beams where recombination become significant in ion chambers. Unlike ion chambers, where the temporal response is limited by the drift velocity of charged particles in gaseous media, it is possible for Ar-scintillation monitors to yield time resolution better than 50 ns.

Unlike intensity monitors which concern themselves only with the full integrated signal, most beam position monitors (BPMs) derive the beam position from difference-over-sum (D/S) of signals measured at opposing locations about the X-ray beam.⁸ The obvious advantage of this method is that it is nearly linear with small changes in beam position and it is independent of the beam intensity to first approximation. A classic example of the D/S method is the photo-electron-based BPM. Ionization chambers with split collector electrodes are commercially available devices for simultaneous beam intensity and position measurement.⁷

We have created an integrated X-ray intensity and beam position monitor based on Ar-scintillation with a relatively compact design. In this work we present our first result to characterize this device and evaluate its usefulness for intermediate and high-energy x-ray applications. It is noteworthy that the compact Ar-scintillation monitor requires no external

power supply, and the length (44.5 mm) is much shorter than a standard ion chamber.

II. EXPERIMENT

The integrated intensity and beam position monitor is shown in Figure 1. In part (a) a cross-section diagram of the device is shown. The X-ray beam enters the device through an opaque foil to minimize background light which affects the performance of the PIN diodes. An ideal foil would be an opaque, amorphous material resistant to radiation damage, but for these tests a 6 μm aluminized Mylar foil was used. The two PIN diodes (Hamamatsu S2744-09S with 10×20 mm active area each) are mounted on the top and bottom of the device facing toward each other. The 99.997 purity N_2 and Ar gas flow at atmospheric pressure was supplied to the monitor cavity through small 1/8 in. push-to-connect tube fittings mounted the side of the device. A photograph of the device is shown in Figure 1(b).

The device was tested at two experimental stations at Cornell High Energy Synchrotron Source (CHESS): at F3 beam line, providing X-rays from a bend magnet source and at A2 beam line where X-rays come from a Wiggler source. The experimental layout is shown in Figure 2(a), and data collection scheme is given in Figure 2(b).

At each of these experimental stations the X-ray beam first passes through an ion chamber (IC0), then a beam defining slit, followed by an additional ion chamber (IC1). The ion chamber active length was 6 cm, and the fill gas was N_2 . Ion chamber currents were amplified using a Stanford Research SR570 current amplifier and monitored using a voltage-to-frequency converter. The beam-defining slit is mounted on a motor-controlled jack; adjustment of the slit height affects both the beam position and intensity. The Ar-scintillation monitor is mounted also on a motor-controlled jack; adjustment of the monitor height affects the apparent beam position but not the beam intensity. The X-ray beam was delivered in both experimental stations via Si (111) double crystal

FIG. 1. (a) The cross-section diagram of the compact Ar-scintillation monitor. (b) Photograph of the actual device.

monochromators. At F3 station, the intensity of 17 keV X rays delivered through a 1×1 mm slit was 1.2×10^9 ph/s. At A2 station, the intensity of 59.7 keV X rays through a 1×1 mm slit was 2.2×10^{10} ph/s.

In Figure 2(b) the diagram of the electronics layout is displayed. The top and bottom PIN diodes were connected directly to two Stanford Research SR570 current amplifiers, that is, they were operated in photovoltaic mode. The current amplifier gain was set to 0.5–1 nA/V and 5 nA/V for the bend magnet (F3) and the Wiggler source (A2), respectively.

The SR570 output voltages from the PIN diodes and the ion chambers were measured using a 24-bit analog-to-digital converter (ADC) sampling at 5000 Hz and recorded via USB connection to a computer. A custom program recorded the signals and calculated the sum and difference-over-sum. The 100–300 data points were averaged, for an effective integration time of 20–60 ms, yielding an improvement in the signal-to-noise ratio by a factor of ~ 12 .

III. RESULTS

A. Performance of the compact Ar-scintillation monitor as an X-ray intensity monitor

We have made X-ray intensity measurement with the Ar-scintillation monitor both at F3 and A2 experimental stations

FIG. 2. (a) Diagram of the experimental setup at CHESS F3 and A2 beam lines, (b) the diagram of the electronics layout: The top and bottom PIN diodes are connected to two Stanford Research SR570 current amplifiers followed by a 24-bit ADC and the data acquisition personal computer.

at 17 keV and 59.7 keV, respectively. The results were entirely consistent, and for the sake of brevity we show the data obtained at A2 only.

In order to test how the compact Ar-scintillation device performs as an X-ray intensity monitor we needed to control the X-ray intensity over a wide range. This was achieved by narrowing the beam-defining the 2 mm wide slit aperture horizontally in 100 μ m steps and simultaneously measuring the ion chamber counts and the compact Ar-scintillation monitor sum signal.

In Figure 3(a) the normalized intensity signals from the ion chamber and the Ar-scintillation monitor are shown on a log scale. The two curves practically overlap and the difference between the ion chamber and Ar-scintillation monitor data evident only at higher magnification shown in the inset. The inset also shows that the ion chamber data show less variation, which we attribute to a longer integration time (100 ms) for the ion-chamber signal. Figure 3(b) plots the linearity of the X-ray intensity as measured using the Ar-scintillation monitor relative to the ion chamber. No significant deviation from linear dependence between the two intensity measurement methods was observed.

B. Performance of the Ar-scintillation monitor as an X-ray beam position monitor

The experiments done in F3 and A2 showed very similar performance, so in the following we will discuss the results obtained at A2 station only. The Ar-scintillation monitor's performance as a BPM was tested as the monitor was moved vertically while the beam defining slit was kept fixed. During the vertical scan both top and bottom signals have been recorded with the calculated D/S values.

In Figure 4(a) we show the results of the performance of the Ar-scintillation monitor as a beam position monitor. The measurements were done at 1×1 mm slit size at 59.7 keV with a photon intensity of 2.2×10^{10} ph/s. The Ar-scintillation monitor was translated vertically in 100 μ m steps while the signals from the top and bottom PIN diodes and the calculated D/S values have been recorded continuously in 300 ms data acquisition steps. The top/bottom signals (shown in blue/red) show the expected step-wise opposite trend as the monitor is moved upward. The spikes at each step are the result of noise generated by the stepping motors that is added to the signals due to inadequate electrical isolation of the device. The black line shows the actual calibrated X-ray beam position derived from the D/S signal of the monitor. (Note that the spikes are not present there as this noise is equally added to the both top and bottom signals.) The precision of the X-ray beam position measured by the Ar-scintillation BPM was found to be 2 μ m, as derived from the standard deviation of the steady (non-moving) segments of the position plot. This number is greater than the resolution (~ 0.5 μ m) of the Ar-monitor as measured using a fixed intensity light-emitting diode light source. We attribute the greater value of measured beam position variability to real beam motion. In Figure 4(b) the linearity of the Ar-scintillation BPM is shown. The dots represent the measured beam position as a function of the known vertical position of the stepping motor.

FIG. 3. (a) Normalized intensity measured with the Ar- scintillation monitor (red) in comparison with the ion chamber intensities. The X-ray intensity was reduced by closing the horizontal slit aperture. (b) Linear dependence between the ion chamber and the Ar-scintillation monitor responses.

FIG. 4. (a) Top and bottom signals from the Ar-scintillation BPM (blue and red) and the X-ray position from D/S (black). (b) The measured beam position as a function of Z-stage height (dots) with the linear fit (red line).

The least-square fit (red line) shows that the monitor has an almost perfectly linear response to the beam position over a span of 2 mm in the vertical direction, which amply covers the expected range of beam motion.

IV. CONCLUSIONS

We have developed and tested a new compact integrated X-ray intensity and beam position monitor based on Ar gas scintillation. The device contains two large-area PIN diodes operating in photovoltaic mode that measure the intensity of the scintillation. The sum of the two signals is used to monitor the beam intensity, while the difference-over-sum of these signals represents the beam vertical position. We found an excellent agreement and linear relationship between the intensities measured using the Ar-scintillation monitor and a standard 6 cm ion chamber with N₂ fill gas.

The Ar-scintillation monitor was found to operate well as a beam position monitor, showing linear response to beam position over 2 mm span, with a precision of 2 μm .

ACKNOWLEDGMENTS

This work is based upon research conducted at the Cornell High Energy Synchrotron Source (CHESS) which is supported by the National Science Foundation and the National Institutes of Health/National Institute of General Medical Sciences under NSF Award No. DMR-0936384.

¹R. W. Alkire and F. J. Rotella, "An incident-beam monitor for use in protein crystallography at a synchrotron source," *J. Appl. Crystallogr.* **30**, 327–332 (1997).

²R. G. van Silfhout, "A high-precision X-ray beam-position and profile monitor for synchrotron beamlines," *J. Synchrotron Radiat.* **6**, 1071–1075 (1999).

- ³R. W. Alkire, G. Rosenbaum, and G. Evans, "Design of a vacuum-compatible high-precision monochromatic beam-position monitor for use with synchrotron radiation from 5 to 25 keV," *J. Synchrotron Radiat.* **7**, 61–68 (2000).
- ⁴A. Kachatkou and R. G. Silfhout, "On the resolution and linearity of lensless in situ X-ray beam diagnostics using pixelated sensors," *Opt. Express* **21**(4), 4292 (2013).
- ⁵R. G. van Silfhout, A. Kachatkou, N. Kyele, P. Scott, T. Martin, and S. Nikitenko, "High-resolution transparent x-ray beam location and imaging," *Opt. Lett.* **36**(4), 570–572 (2011).
- ⁶N. Kyele and R. G. van Silfhout, "In situ synchrotron x-ray photon beam characterization," *J. Appl. Phys.* **101**(6), 064901 (2007).
- ⁷T. Gog, D. M. Casa, and I. Kuzmenko, "Initial tests of a position-sensitive ionization chamber," (CMC-CAT @ the APS), see http://www.aps.anl.gov/Sectors/Sector9/Operations/9id_manual/equipment/detectors/ionchambers/notes.pdf.
- ⁸D. Shu, B. Rodricks, J. Barraza, T. Sanchez, and T. M. Kuzay, "The APS x-ray undulator photon beam position monitor and tests at CHESS and NSLS," *Nucl. Instrum. Methods Phys. Res. A* **319**, 56 (1992).
- ⁹M. Suzuki, H. Toyokawa, and K. Hirota, "High flux X-ray beam intensity monitor based upon rare gas scintillation," *AIP Conf. Proc.* **705**, 580–583 (2003); *Eighth International Conference on Synchrotron Radiation Instrumentation 25–29 August 2003*, San Francisco, CA, USA.