AN APERTURE BACKSCATTER X-RAY BEAM POSITION MONITOR AT DIAMOND

C. Bloomer, G. Rehm, C. Thomas, Diamond Light Source, Oxfordshire, UK

Abstract

This paper presents the design and first results of a new XBPM developed at Diamond that images the photon backscatter from a Front End absorber to measure the beam centre of mass. This is of particular interest for monitoring the emission from elliptically polarising undulators where the profile of the beam varies strongly with change of beam polarisation. Traditional four-blade Front End XBPMs struggle to resolve a beam centre of mass for EPUs because of this. We have developed an XBPM that observes the backscattered photons from a copper aperture through a pinhole. This solution is capable of operating with the full white beam, and has been designed to fit into the same physical space as the standard front end XBPMs in use at Diamond. This offers the potential to easily replace traditional XBPMs where beneficial and required.

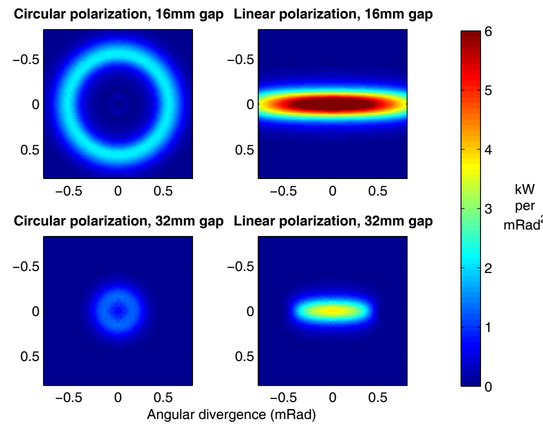

Figure 1: The beam intensity and distribution varies between polarisations and gaps.

INTRODUCTION

Tungsten vane X-ray Beam Position Monitors (XBPMs) can be designed to perform well for most X-ray beam distributions. However, frequently changing or none-Gaussian beam shapes cause problems for fixed-blade monitors. In particular, Elliptically Polarising Undulators (EPUs) produce such a wide range of photon distributions that fixed blade monitors are of little use. Attempts have been made to resolve this problem using moving-blade arrangements [1], but such devices are complex to operate and maintain. An ideal beam position monitor would be able to cope with any beam shape, and none-destructively monitor the beam.

Fluorescent screens are a valuable diagnostic tool on beamlines, often used to monitor monochromatic X-ray beams in situ. This removes the problem of using four fixed blades as detectors as one can image the entire beam shape. Fluorescent screens have a tendency to deteriorate quickly under high flux though, if they survive at all, limiting their use as long-term white-beam position monitors.

A more recent development is the use of thin scattering foils placed into the X-ray beam path [2] [3]. This has the advantage that the uniform foil does not deteriorate over time as fluorescent screens do. The X-ray beam strikes the foil which is transparent to the majority of photons. A small amount of the total flux is elastically scattered by the foil and the scattered X-rays are then spatially imaged through pinholes or Soller slits.

However, both of these methods have the drawback that the screen or foil used will unavoidably absorb a portion of the beam, with low energy photons the most likely to be absorbed. This presents a particular problem for EPUs, which typically have a first harmonic as low as just a few 10s of eV, and the flux is predominantly made up of low energy photons.

DESIGN OF A NEW XBPM

In recent years a significant effort has gone into the development of new photon diagnostics techniques with high spatial resolution of the beam profile [4] [5]. The development of a new type of XBPM at Diamond Light Source was required to accurately measure the beam position for EPU beamlines. The first such beamline at Diamond, I06, uses a 64mm period APPLE II EPU capable of producing a large range of beam distributions (Fig. 1). The first harmonic at minimum gap is 103eV in circular polarisation and 74eV in linear polarisation. At this energy a foil even just a few microns thick is enough to absorb most of the incident user photons. If this technique is to be used then an aperture must be cut in the material in order to allow the user light through the centre, but even so the majority of the halo photons that would strike the foil are still $<$1keV.

This causes an unusual problem: large amounts of power is deposited into the foil, not because the photon energies are high, but specifically because the photon energies are *very low*. Even relatively transparent thin carbon foils become opaque to the low energy photons in the I06 halo (Fig. 2). Finite Element Analysis (FEA) simulations show that a water-cooled 200 micron diamond screen would reach $>$1000 degrees Celsius, absorbing a large por-

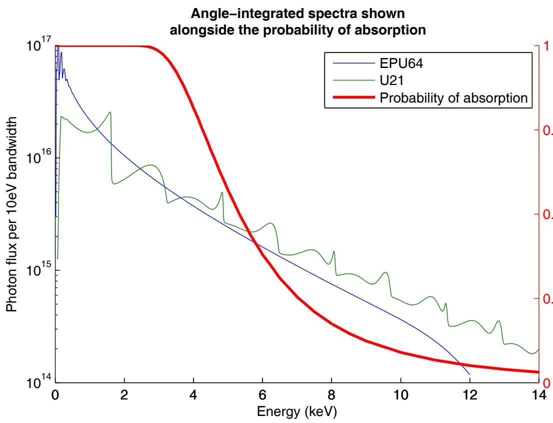

Figure 2: Shown is the integrated spectra of the I06 EPU64, circular phase and 16mm gap, and an in-vacuum U21 at 5mm gap. The U21 spectra contains more photons at high energies, but the EPU64 has more photons at low energies where they are more readily absorbed. The calculated absorption rate for a 200µm thick carbon foil is shown.

tion of the 4.1kW X-ray beam produced by the I06 undulator at 300mA stored beam.

A suitable alternative was found by simulating the effects of the I06 beam striking a shallow-angle copper wedge. A 10mm diameter hole in the centre of the aperture allows the user photons to pass through, while its large mass and thermal conductivity aids heat dissipation. This design went through several iterations until the material stress was found to be acceptable. Considerable effort was put into finding an aperture design that could withstand the white beam under all conditions, especially given that the new XBPM had to fit into the same physical Front End space as the old tungsten blade XBPM.

In the centre of the wedge is the main hole to allow the user photons to pass through, a keyhole shaped aperture is used to reduce the thermal stress on the material. The cooling water supply is fed through the wedge, 5mm under the scattering surface, to increase the removal of heat.

In order to resolve the spatial distribution of the scattered photons some form of optics are required. Since it was desired to keep the design as simple as possible a 25µm diameter pinhole was used to image the beam distribution onto a fluorescent screen, in-vacuum. The scattered X-rays striking the screen produce visible photons that pass out of the vacuum vessel through an optical viewport. A standard GigE camera with a high quality lens was used as the out-of-vacuum detector.

INITIAL RESULTS

Initial results from the XBPM were disappointing as the detector was saturated with visible and UV light (Fig. 3A), a possibility that had not been taken into account during the design of the monitor. This light was found to be coming from in-vacuum vents between the pinhole and the fluorescent screen, vents that had been added to the design to

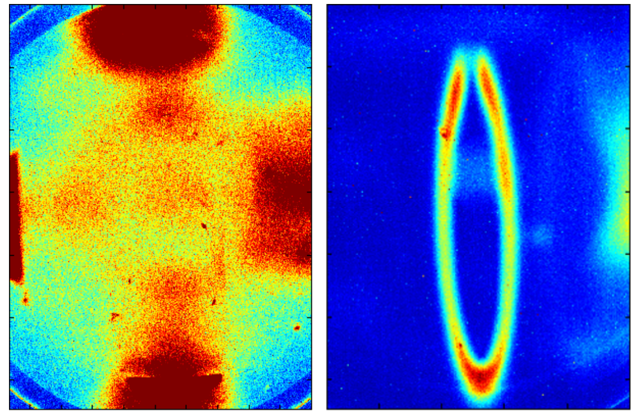

Figure 3: A, left: The first image from the XBPM, saturated by visible and UV light. B, right: The image seen after baffles and larger pinhole were installed. Both show the EPU64 at 16mm gap and circular phase.

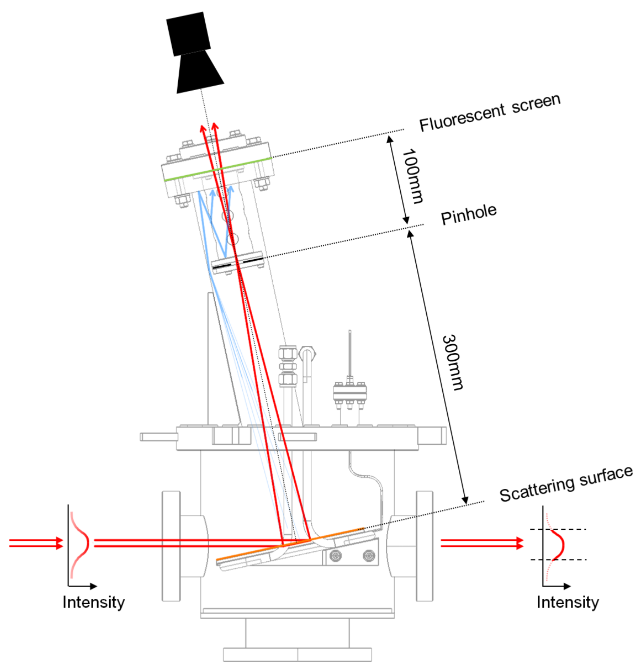

Figure 4: Schematic of scattering optics. The pinhole and the fluorescent screen are in-vacuum, and visible light from the screen is viewed with a GigE camera through an optical viewport. The red lines show the expected path of the X-rays, scattered by the surface of the copper aperture. The blue lines show the likely path that the visible light was taking through the vent holes inside the XBPM.

prevent a trapped space of air behind the pinhole (Fig. 4).

This large amount of visible light was drowning out the scattered X-ray photons that we expected to see, so two improvements were made to the design. Firstly, a baffle was installed in order to block the path of visible light coming from the in-vacuum vents, and secondly the pinhole was exchanged for a larger, 1mm diameter pinhole. The addition of a larger pinhole was a compromise, reducing the spatial resolution of the image in exchange for ensuring that enough scattered X-rays reached the screen.

These adaptions had the desired effect and the subsequent images were of much higher quality. Figure 3B shows the EPU64 X-ray beam at circular phase after the modifications. Clearly visible is the ring of photons typical of this undulator when producing circularly polarised light (as seen in Fig. 1). The image is elongated vertically due to the grazing angle of the copper aperture relative to the incident beam.

POSITION MEASUREMENTS

A 1.0s integration period is used for the pinhole image, and using a simple 2D centre of mass calculation the beam position can be found with a resolution of <10μm. Greater resolution can be achieved using longer integration periods. The vertical beam position can be found with greater resolution due to the magnifying effects of the angled aperture.

Both XBPM stepper motor movements and electron beam bumps were separately used to offset the incident X-ray beam, both giving very consistent results. Scans were made over a 1.0mm range and beam movements were accurately detected using simple 2D centre-of-mass fitting. The data shown in Fig. 5 is from linearly polarised light, 16mm gap.

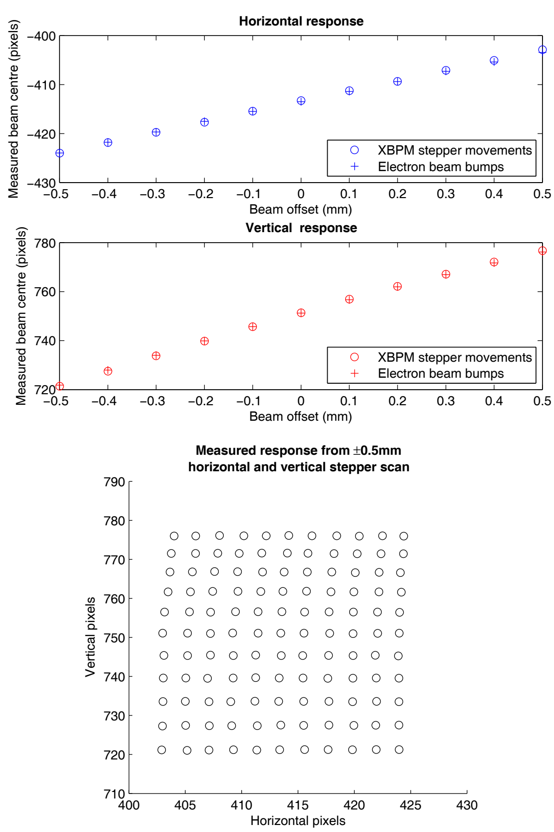

Figure 5: First position measurements made using the Aperture XBPM.

CONCLUSIONS

This type of XBPM has several advantages over other types of monitor. Compared to tungsten vane XBPMs the spatial resolution afforded by this monitor provides far more information regarding the photon beam distribution, over a larger linear range, and helps to overcome gap-dependant effects. The in-vacuum pinhole design with an out-of-vacuum detector is a very simple solution compared to other monitors that utilise in-vacuum detectors, and avoids the need for elaborate (and expensive) in-vacuum electronics and feed-throughs. The size of the XBPM and its simplicity make it an excellent substitution for Front Ends where existing XBPMs have thus far proved unsuitable.

The initial prototype described here could however be improved. Presently a 10mm diameter central aperture is used to allow user photons through, this could be significantly reduced in size. A smaller 5mm diameter aperture would scatter more X-rays, improving the resolution of the device, yet this would still allow user photons to pass through. The 1mm pinhole used to record the measurements presented here could in all likelihood also be made smaller, improving the resolution of the optics at the cost of detecting fewer photons. A 1.0s integration time is sufficient to monitor slow drifts, but not fast enough to monitor beam vibrations. Better quality detectors with a larger optical lens could be used instead of standard GigE camera in order to improve this.

One final drawback to this type of monitor is the inability to use two, spatially separated by some metres, in order to measure relative angular changes. The beam periphery is entirely absorbed by the monitor, so a downstream monitor would have nothing left to view. However, a standard XBPM could be used upstream, followed by a downstream Aperture XBPM. Results from the two could be combined to provide angular information.

REFERENCES

[1] H. Aoyagi, T. Kudo, and H. Kitamura. Blade-type X-ray beam position monitors for SPring-8 undulator beamlines. *Nuclear Instruments and Methods in Physics Research A*, 467:252–255, July 2001.

[2] R.G. van Silfhout, S. Manolopoulos, N.R. Kyele, and K. Decanniere. In situ high-speed synchrotron x-ray beam profiling and position monitoring. *Sensors and Actuators A: Physical*, 133(1):82 – 87, 2007.

[3] Nicholas R. Kyele, Roelof G. van Silfhout, Spyros Manolopoulos, and S. Nikitenko. In situ synchrotron x-ray photon beam characterization. *Journal of Applied Physics*, 101(6):064901, 2007.

[4] P. S. Yoon and M. P. Siddons. Photodiode-based X-ray Beam Position Monitor with High Spatial-resolution for the NSLS-II Beamlines. In *Proceedings of DIPAC09*, 2009.

[5] B. X. Yang, G. Decker, S. H. Lee, and P. Den Hartog. High-power Hard X-ray Beam Position Monitor Developement at the APS. In *Proceedings of BIW10*, 2010.