Study of X-ray Fresnel Diffractometry for Small Beam Sizes at Diamond Light Source

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ABSTRACT

The feasibility of X-ray Fresnel diffractometry in measuring small beam sizes beyond the resolution of X-ray pinhole cameras is studied in the case of Diamond Light Source. After the Diamond-II upgrade, beam sizes as small as 4 µm are anticipated and are not resolvable by the X-ray pinhole cameras [1], which are the workhorse for beam size, emittance, and energy spread measurements. X-ray Fresnel diffractometry employs a single aperture with an optimised width, producing a double lobe diffraction pattern. The visibility of this double lobe intensity distribution relates to the beam size and promises micron-scale beam size measurement. Numerical studies and simulations have been conducted to assess the feasibility of diffractometry for Diamond Light Source. The parameters for the experimental setup have been determined and preliminary experimental results are presented. Challenges and improvements for achieving this measurement for Diamond-II are discussed.

X-RAY FRESNEL DIFFRACTOMETRY

X-ray Fresnel diffractometry involves observing a double-lobed diffraction pattern produced by an aperture with width A. The correlation between the extent of the central dip in the diffraction pattern and the electron beam size is used to determine the electron beam size [2].

For a spherical wave with a flux distribution broader than the aperture width, the Point Spread Function (PSF) at the screen is given in one dimension by the Fresnel integral [3, 4]:

$$I(y, y_e) \propto \left| \int_{-A/2}^{A/2} \sqrt{(I(y_s - y_e)}\, e^{\frac{ik}{2z}(y_s - y_e)^2} e^{\frac{-ik}{2R}(y - y_e)} dy_s \right|^2$$

where $\sqrt{(I(y_s - y_e)}$ is the radiation intensity distribution in the aperture plane, $k = \frac{2\pi}{\lambda}$ where λ is the wavelength, y_e is the electron position at the source point, y_s and y are the coordinates on the aperture and the screen and $z = RL/(R+L)$ where is the source-to-aperture distance L and the aperture-to-screen distance R.

To achieve a double-lobed PSF, the aperture width A should be optimised by taking into account the monochromatic light source with wavelength λ, the distances L and R, [2] :

$$A \approx \sqrt{7\lambda \frac{L \times R}{L + R}}$$

NUMERICAL CALCULATIONS

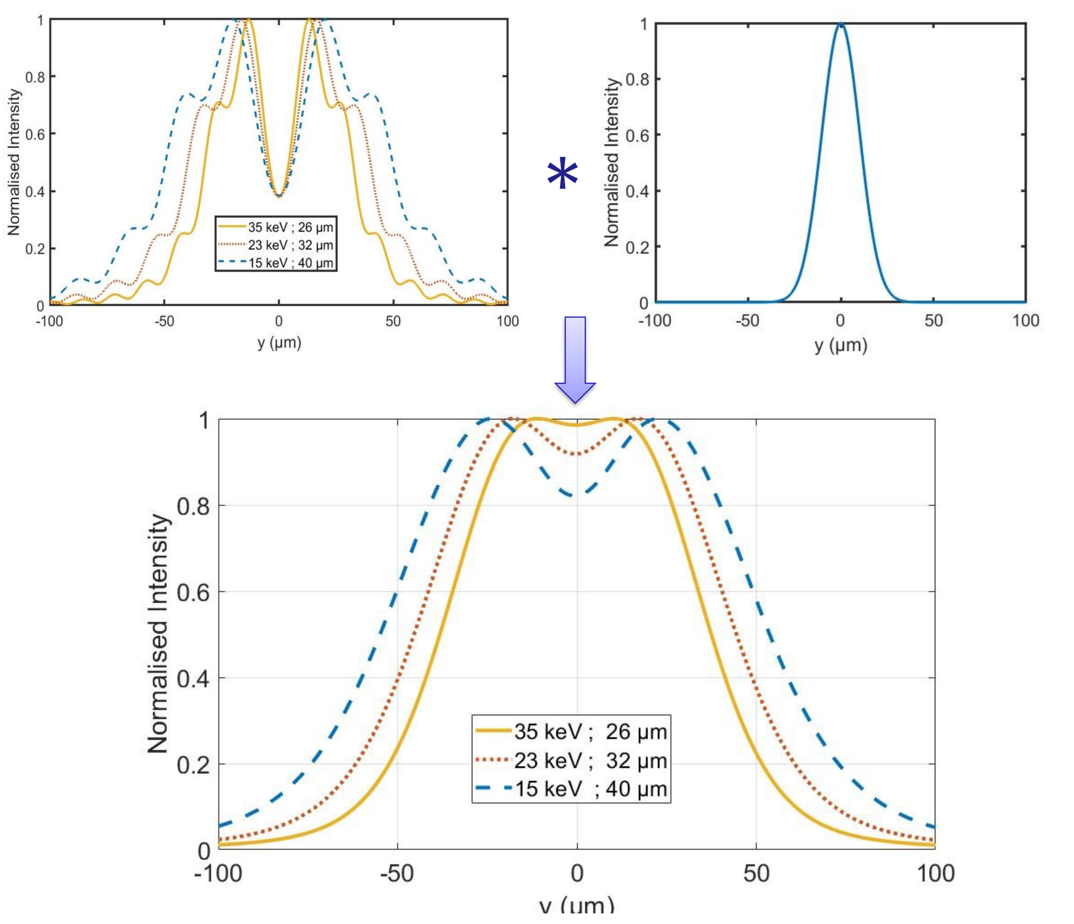

***Figure 1**: Fresnel PSF convoluted with Gaussian distribution source with 4 µm beam size taking into account the source-to-screen magnification and the PSF from the screen, lens and sensor for different energies and optimised apertures*

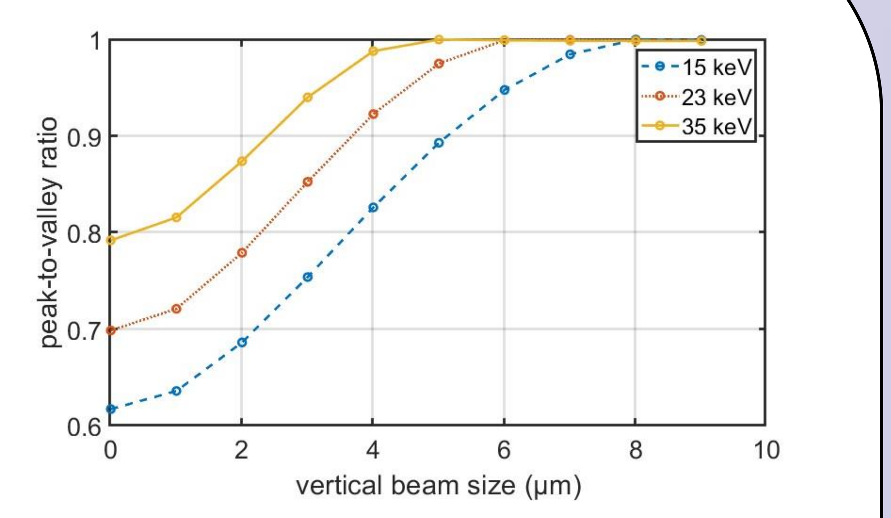

***Figure 2**: Peak-to-valley ratio of observed diffracted pattern versus the vertical beam size for different X-ray energies for the case of Diamond.*

Low energy X-rays passing through wide apertures provide a double-lobed distribution whose visibility (i.e.peak-to-valley ratio) is sensitive to a broader range of electron beam sizes.

EXPERIMENTAL SETUP

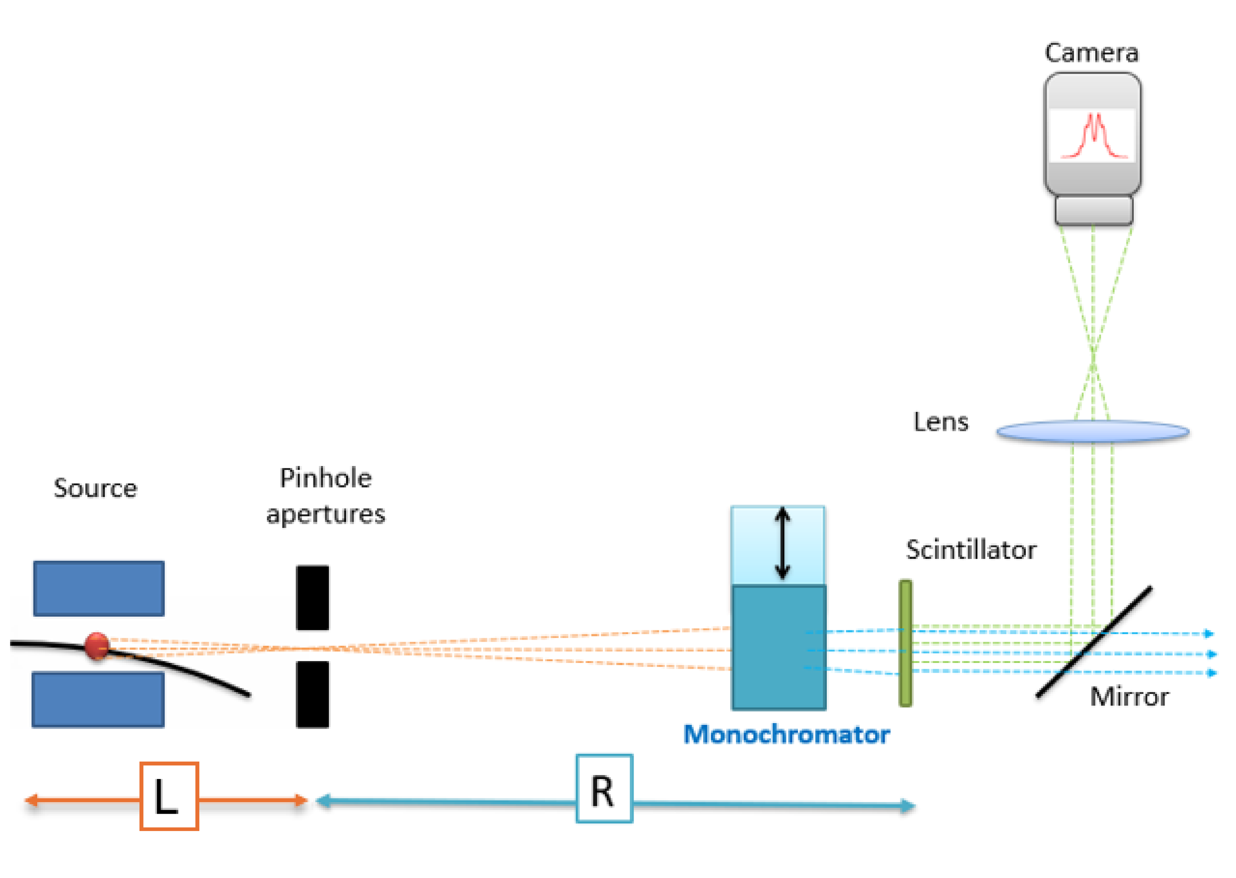

***Figure 3**: Experimental setup of existing pinhole camera system used to test X-ray Fresnel diffractometry.*

- LIGA square apertures around 40 µm [5].
- Distances L = 3.82, R= 9.72
- The spectral bandwidth of the exit beam when using a multilayer monochromator is 2% at 15 keV [6].
- Gadolinium aluminium gallium garnet doped with cerium (GAGG+) scintillator. [7].
- Manta G319B camera.
- The PSF of the camera includes contribution from the screen, the lens and the sensor estimated to be 8 µm.

DIAMOND-II

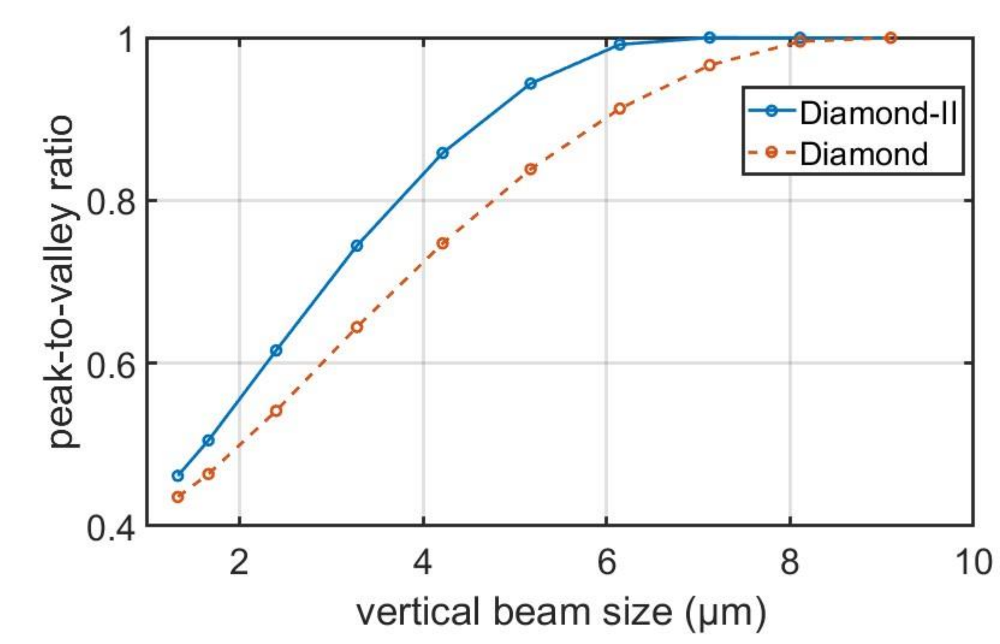

***Figure 4:** Peak-to-valley ratio of observed diffracted pattern versus the vertical beam size for Diamond and Diamond-II for a monochromatic X-ray beam at 15 keV.*

- Diamond-II power spectrum is between 15 keV to 60 keV (similar to Diamond) but the aperture will be installed closer to the source point. (L =2.7, R =13.3)
- The Diamond-II setup will provide enhanced resolution for small beam sizes due to its sharp sensitivity curve.

EXPERIMENTAL RESULTS

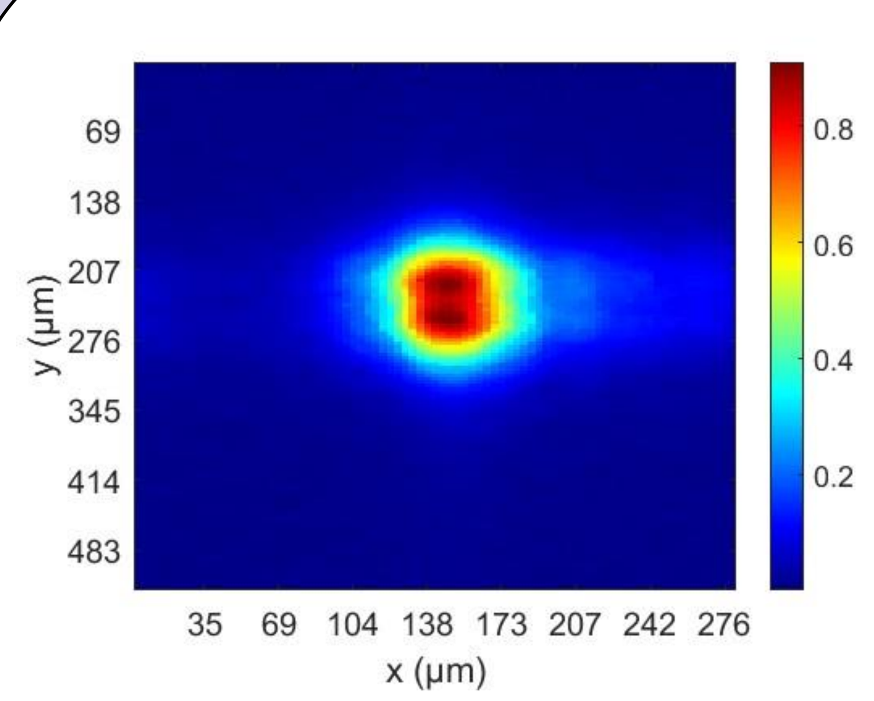

***Figure 5** : Measured intensity distribution with diffraction pattern present formed by an aperture with 37 µm width.*

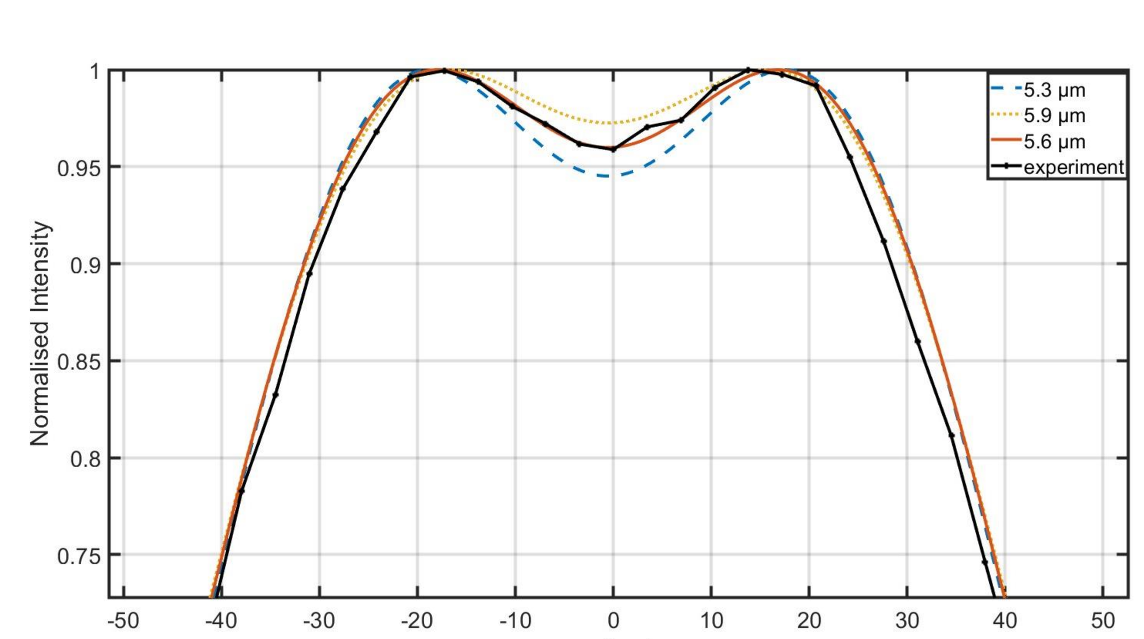

***Figure 6** : Normalised vertical projected profile of Fig. 5 in black dotted line and fitted curves for 5.3 µm 5.6 µm 5.9 µm.*

- The vertical profile of the diffraction image area where the normalised pixel values are higher than 0.8 is plotted in Figure.
- X-ray diffractometry technique provides a sub-micrometer level resolution.
- The measured vertical beam size is consistent with the beam size reported from other pinhole cameras located in the storage ring.
- The spatial resolution of the imaging system must be enhanced as the expected intensity change is small (0.95).

CONCLUSIONS

- X-ray Fresnel diffractometry was successfully employed at Diamond, demonstrating good agreement with numerical calculations.
- The beam size measurement also, aligned well with results obtained from other pinhole cameras in the storage ring.
- According to the numerical calculations, lower energies with optimised apertures demonstrated sensitivity to a broader range of beam sizes. However, for higher energies and smaller apertures, the resolution improves.
- This study served as a benchmark for the design of the experimental setup for this technique in Diamond-II and the integration of the additional components to the beamline to allow this measurement to complement the pinhole cameras for small beam sizes will be considered in the design of the beam size monitors for Diamond-II.

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