Wavefront Analysis by Shadow Raytracing Program

***Hossein Khosroabadi*, David Laundy, Vishal Dhamgaye, Kawal Sawhney**

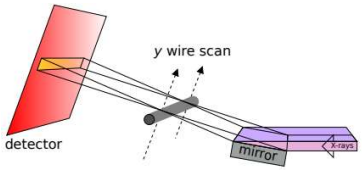
Optics & Metrology Group, Diamond Light Source, Oxfordshire, UK

Introduction

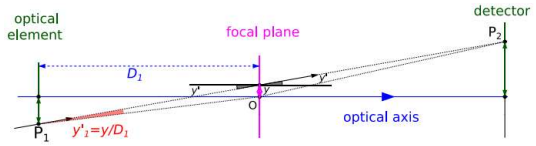
- Wavefront sensing is a useful method to measure and correct wavefront imperfection in diffraction limited sources
- Variety of methods, including the knife-edge imaging technique developed at Diamond light source, have been used for wavefront sensing
- Here, a simulation method is developed based on the knife-edge technique to:
  - Investigate wavefront error of a specific focusing optics
  - Design of the wavefront corrector
  - Help in optical layout design with minimum wavefront distortion, etc

Knife-edge Imaging Technique

- To step an absorbing knife-edge into the beam while measuring the transmitted intensity on a 2D x-ray detector positioned downstream [2]
- The technique has been successfully applied for the wavefront measurement & alignment of a KB mirror, correction of wavefront error by refractive correctors [1], and recently to optimize the wavefront of X-ray Alvarez lens [2]



Schematic layout: Focusing optics, knife-edge, and 2D pixel detector



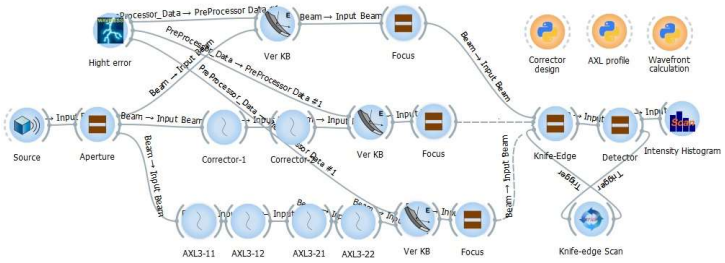
Wavefront calculation: The measured intensity on pixel P2 is projected back to obtain wavefront angular distortion of y'_1

Verification of the Method

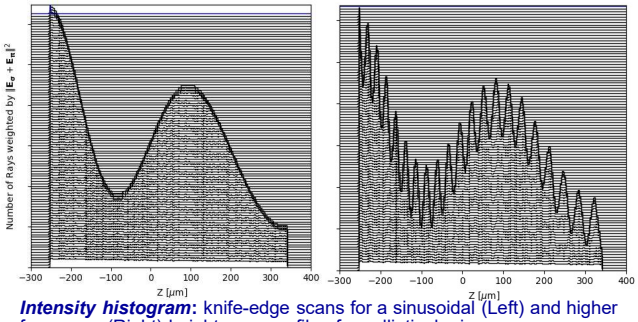
- The calculated wavefront matches well with the measured data obtained on B16 beamline at Diamond
- Zero-coma line of the KB grazing angle and shearing of Alvarez lens has been experimentally verified [2]

Raytracing Method

- Setup the beamline/experiment (source, focusing optics, knife-edge, detector) in Shadow (OASYS) [3]
- Calculate the Intensity histogram on a downstream pixel-detector
- Scan the knife-edge through the focal spot & finding the edge
- Calculate the wavefront error and its polynomial coefficients [1] by additional developed program in OASYS



Beamline layout: wavefront calculation by knife-edge technique for KB mirror (Top); combined KB & wavefront corrector (Middle); combined KB & Alvarez lens (Bottom)



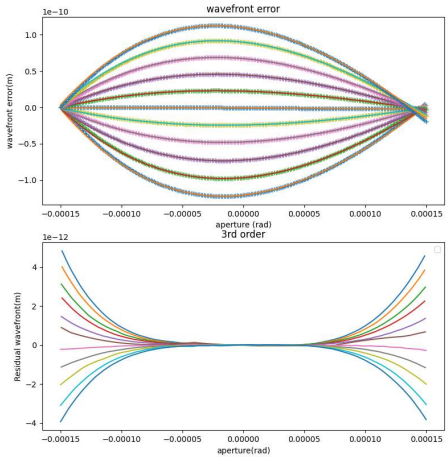
Intensity histogram: knife-edge scans for a sinusoidal (Left) and higher frequency (Right) height error profile of an elliptical mirror

Advantages

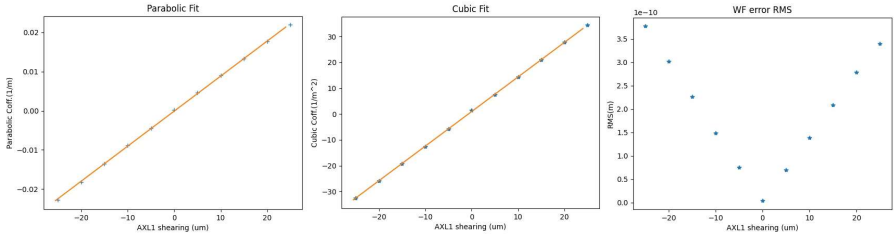
- Quick way of the wavefront analysis for a variety of focusing optics
- Design and prediction of the wavefront correction by a refractor structure
- Optimize the experimental setup parameters to minimize the coma aberrations
- Save considerably on the experiment time and efforts, and useful for automatic alignment of the focusing optics

Outcome & Applications

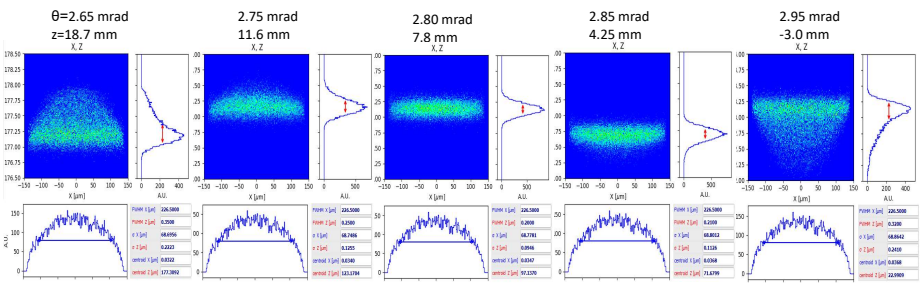
- To optimize the beamline layout by minimizing the parabolic, cubic and residual RMS wavefront error for a focusing optics
- To design a specific/generic refractor corrector for minimizing the wavefront error in the diffraction limited condition
- To correct the parabolic and coma aberrations of the x-ray Alvarez lens by adjusting the mirror pitch angle and Alvarez shearing [2]



Optics Alignment: calculated wavefront error (Top); its residual higher orders after parabolic & cubic subtraction (Bottom)



AXL calibration: Parabolic & cubic calibrations and RMS wavefront error for x-ay Alvarez lens



Focal profile: Parabolic & cubic corrections for x-ay Alvarez lens give free-aberration vertical focal profile (Middle plot)

References

[1] Adaptable refractive correctors for X-ray optics; D. Laundy, V. Dhamgaye, T. Moxham, & K. Sawhney, Optica **6**, 1484 (2019).

[2] An Alvarez varifocal X-ray lens; V. Dhamgaye, D. Laundy, H. Khosroabadi, T. Moxham, S. Baldock, O. Fox, and K. Sawhney, Nature Com. **14**, 4582 (2023).

[3] OASYS: A software for beamline simulations and synchrotron virtual experiments; M. Sanchez-del Rio, and L. Rebuffi, AIP Conf. Proc. **2054**, 060081 (2019).

Contact: *For further information please contact Hossein.khosroabadi@diamond.ac.uk*

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