Wavefront Sensing of an Extreme-Ultraviolet Free-Electron Laser

Niranjan Kannali Ramesha, Mabel Ruiz Lopez, Christian Rödel

SCHMALKALDEN UNIVERSITY OF APPLIED SCIENCES
Fakultät Maschinenbau
Physik und angewandte Lasertechnik

Introduction

The Free electron laser in Hamburg (FLASH) is the world's first Extreme-Ultraviolet (EUV) and soft x-ray free-electron laser available to the photon science community since 2005. The FLASH particle accelerator can provide a wavelength range between 52 and 4 nm. In this collaboration, we investigate the potential of FELs (Free Electron Lasers) Focused using a Schwarzschild objective for photolithography. [1,2,3]

The FLASH Beamline

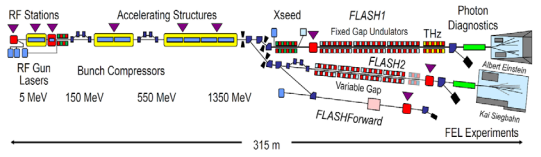

Fig.1 FLASH Beamline at DESY

- The FLASH facility operates with two SASE beamlines in parallel: FLASH1 and FLASH2.
- Our Experiment is carried out at the FLASH2 beamline operating in the EUV regime (13.5nm wavelength).

Specifications: Schwarzschild Objective (SSO).
We create a virtual model of the SSO designed by Zastrau [4].

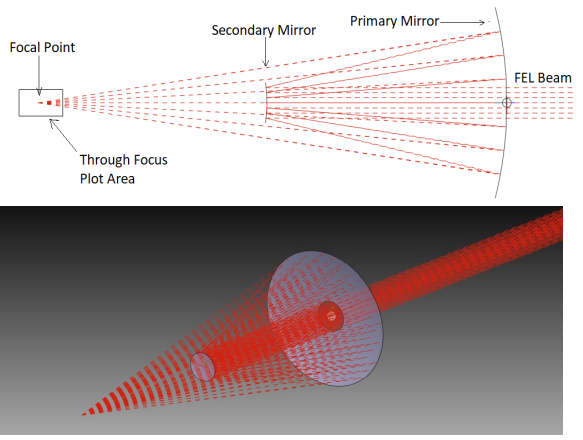

Fig.2 Ray diagram and Cad model of SSO

MIRROR 1(Primary)—concave	
Large mirror diameter D1 (mm)	50 (0.1)
Thickness at edge d (mm)	9.5 (±0.1)
Radius of curvature (RoC) R1	100 mm (±0.5%)
RoC error	±1%
Hole diameter in large mirror (mm)	10.8 (±0.1)
Surface accuracy η	λ/30
Surface roughness σ	<0.25 nm rms
MIRROR 2(Secondary)—convex	
Small mirror diameter D2 (mm)	10.6
Thickness in center d (mm)	6.35 (±0.1)
Radius of curvature (RoC) R2	35 mm (±0.5%)
RoC error (%)	±1
Surface accuracy η	λ/30
Surface roughness σ	<0.25 nm rms

Objective

Recreate a digital twin of the wavefront Measured at DESY (absolute value of all the aberrations in the optics and wavefront defects) and employ this virtual wavefront in a simulation to find the smallest point (Focal point) in the beam line using a Through Focus plot.

Wavefront Measurement Using a Hartmann Wavefront Sensor (HWS)

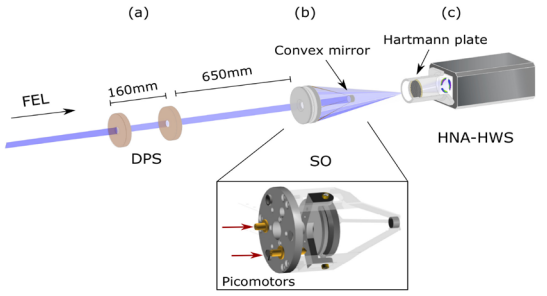

Fig 3. Experiment setup at FLASH. (a) Radiation clipped by aperture set (differential pumping stage, DPS) in front of Schwarzschild objective. (b) Schwarzschild optics reflects the radiation from FEL and (c) focuses it upstream of the Hartmann plate of the Hartmann wavefront sensor (HWS).

A HWS consists of a Hartmann plate and a CCD camera. The Hartmann plate is a perforated plate with a 36 mm diameter. Each hole is projected onto the sensor. The Camera resolution is 2048 × 2048 pixels, with a 13.5 µm pixel size.

Wavefront Reconstruction

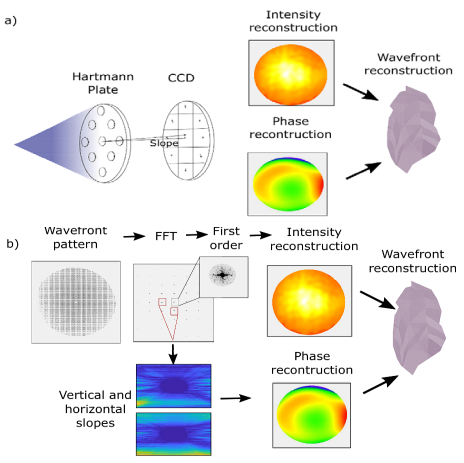

Figure 4. (a) Classical centroid method based on measuring relative position change of geometrical center of intensity of each pinhole in Hartmann array to obtain an estimate of the local wavefront slope. (b) Fourier demodulation based on the fact that an aberrated wavefront modifies grid periodicity; therefore, the wavefront can be calculated through Fourier transformation. Algorithm has four stages: (i) Fourier transforming measured intensity pattern, (ii) isolating first vertical and horizontal side lobes, (iii) centering lobe, and (iv) transforming it back to receive corresponding slope components.

Wavefront Characterization using Zernike Polynomials

- Once the wavefront reconstruction is complete, we break it down to it basic Zernike coefficients.
- We can then use these coefficient to reconstruct the wavefront for our simulations and further fulfill the objective.

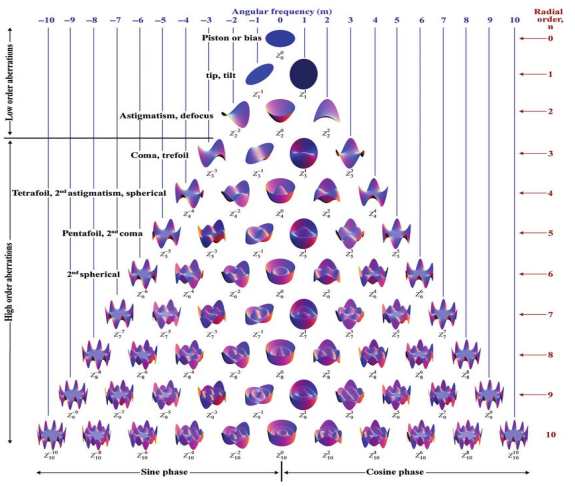

Fig.4 Surface lots of Zernike polynomials up to 10 orders [5]

Analysis Of The SSO with Quadoa

With the obtained wavefront we can now move along to obtain a through-focus plot of the SSO

Through Focus Plot

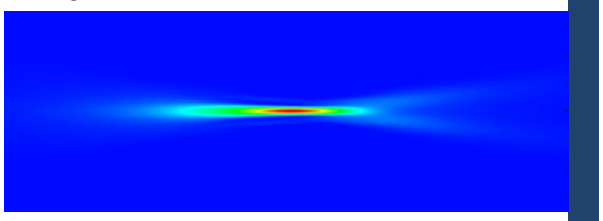

Fig.5 Through focus plot (linear scale)

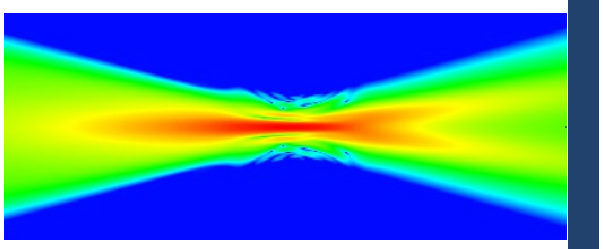

Fig.6 Through focus plot (logarithmic scale)

The Pixel co-ordinates of the spot with the least diameter is read from the pictures above and are converted to Z distances which will in turn give us the co-ordinate of the focal point.

REFERENCES

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[5] https://www.researchgate.net/figure/Surface-plots-of-the-Zernike-polynomial-sequence-up-to-10-orders-The-name-of-the_fig2_241585467