Probing the transverse coherence of an undulator X-ray beam using brownian particles

M. Giglio
University of Milan

University of Milan
Marco A.C. Potenza
Matteo D. Alaimo
Michele Manfredda

ESRF, Grenoble
Theyencheri Narayanan
Michael Sztucki

DESY and European XFEL, Hamburg
Gianluca A. Geloni
Visibility: \[ V = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} \]

Complex coherence factor:

\[ \mu(P_0, P_1) = \frac{\langle E(P_0)E^*(P_1) \rangle}{\sqrt{\langle I(P_0) \rangle \langle I(P_1) \rangle}} \]

\[ V = |\mu(P_0, P_1)| \]
M. Born and E. Wolf, 
Principles of Optics
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\[ < E(x_1, y_1)E^*(x_2, y_2) > \propto \int \int I(\xi, \eta) \exp \left[ i \frac{2\pi}{\lambda z} (\xi \Delta x + \eta \Delta y) \right] d\xi d\eta \]

Average size of a coherent patch generated by a thermal source (Van Citter-Zernike theorem)

\[ d \sim \frac{\lambda}{\Theta} \sim \frac{\lambda z}{D} \]

The shape and the size of the coherent patches at the sensor plane depend only on the profile of the source.
Testing coherence with small spheres

450 nm
Intensity distribution

\[ I = |E_0 + E_s|^2 = |E_0|^2 + 2\text{Re}(E_0 E_s^*) + |E_s|^2 \]

- Incident wave
- Transmitted wave
- Scattered wave

Interference fringes

Transmitted
Interference (Heterodyne)
Homodyne
Simulated coherence patches from the synchrotron

Intensity

Temporal coherence:
\[ \tau_C = 10^{-17} \text{ sec} \]

Phase
t: exposure time

$\tau_C$: temporal coherence

$\tau_C = 10^{-17}$ sec
Scattering with partially coherent radiation

Heterodyne near field X-rays speckles generated by a water suspension of colloidal silica

\[ I = |E_0 + E_s|^2 = |E_0|^2 + 2 \text{Re}(E_0 E_s^*) + |E_s|^2 \]

Transmitted

\( \text{Interference (Heterodyne)} \)

\( \text{Homodyne} \)
Experimental setup – ID02 ESRF

High $\beta$ undulators

Primary Slits (300 x 300) $\mu$m$^2$

Si-111 monochromator

$\frac{\Delta \lambda}{\lambda} = 10^{-4}$

Toroidal mirror

Sample

Phosphor + Objective

Source output

FWHM (945 x 18) $\mu$m$^2$

Phosphor equivalent pixel size: 0.28 $\mu$m
$I = |E_0|^2$
\[ I = |E_0|^2 + 2 \text{Re}(E_0 E_\text{s}) \]
Courtesy of: Gerd Weigelt
Max-Planck-Institut für Radioastronomie, Bonn
280 \mu m

Cosmetics
\[ S(q) = I(q) \ T(q) \ P(q) \ C(q) + \text{noise} \]

\( I(q) = \) Brownian particles form factor (almost flat)

\( T(q) = \sin^2(q^2z/2 \ k) \)
Talbot transfer function

\( C(q) = |\mu|^2 \)

\( P(q) = \) Sensor transfer function
Autocorrelation

Speckle field

5 mm
28 mm
68 mm

98 mm
138 mm
208 mm

10 μm
140 μm
Calibration

5 mm

48 mm

$P(q)$

$S(q)$

noise

Amplitude (a.u.)

$q (\mu m^{-1})$
$$r = z \theta = z \frac{q}{k}$$
2D visibility
Near Field Speckles

Beam

Scatterer

\( D \)

\( z \)

\( \Delta z \)

\( a \)

\( d_{sp} \approx a \)

(depth of focus)

\( 2z_R \)

\( z_R \approx \frac{a^2}{\lambda} \)

\( 2z_R \)

\( \Delta z \)
Double frame analysis

\[ \delta f(r, t, \tau) = f(r, t + \tau) - f(r, t) \approx 2 \text{Re} \left\{ e_s(r, t + \tau) - e_s(r, t) \right\} \]

Fourier Transform

\[ I(q, \tau) \equiv |\delta F(q, \tau)|^2 \approx I(q) - \text{Re} \left\{ E(q, t) E^*(q, t + \tau) \right\} \]

Static information

Dynamic information