Two Dimensional Synchrotron Radiation Interferometry at PETRA III

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Introduction

Synchrotron radiation interferometry is widely used at modern light sources in order to measure transverse electron beam sizes. The technique is based on probing the spatial coherence of synchrotron radiation in the visible spectral region. The light source PETRA III at DESY (Hamburg, Germany) used this type of interferometer since several years in order to resolve vertical emittances of about 10 pm.rad. In order to overcome some inherent disadvantages in this setup, a new optical diagnostics beamline was recently commissioned with a two-dimensional interferometer, thus allowing to measure beam sizes in both transverse planes simultaneously. This contribution summarizes the status of the interferometer setup and describes studies concerning the possibility to increase the sensitivity on small beam sizes using an intensity imbalance technique.

Principle

The principle of the method is based on investigation of the spatial coherence of SR. In order to quantify the coherence properties, usually the first order degree of mutual spatial coherence \(\gamma(D)\) is used

\[
I(y) = I_0 \left( 1 + \frac{1}{\gamma^2} \right) \left[ 1 + \left( \frac{y}{\gamma \lambda_0 R} \right)^2 \right]^{1/2}
\]

Van Zijtt - Zernike:

\[
\gamma(y) = \int y f(y) \exp(-2\pi i y) \, dy, \quad \text{with} \quad \gamma = \frac{D}{\lambda_0}
\]

Gaussian beam profile:

\[
\sigma_y = \frac{\lambda_0}{x D} \sqrt{\frac{1}{2 \ln(2)} - \frac{1}{y D}}
\]

Intensity Imbalance Technique

Limitation of a conventional interferometer is the dynamic range when measuring ultra low emittance beams with visibilities close to unity such that the trowgus are located in or close to the noise floor of the CCD camera recording the interferograms.

Proposal T. Mitsuhashi (KEK): improve situation by introducing intensity imbalance in one of the light paths

First implementation (1-D interferometer):

M. J. Boland, T. Mitsuhashi et al., Proc. IBIC’72, Tsukuba, Japan, WECC03, p. 566 – 570 (2012).

Example: vertical imbalance \(\rightarrow\) pinholes 1 and 2 are “attenuated”

Correction of degree of coherence \(\gamma\) from measured visibility \(V\) in order to get information about true beam size:

\[
\gamma = \left( 1 + \frac{1}{K} \right) V, \quad \text{with} \quad K = \frac{I_1 + I_2}{I_1 I_2}
\]

Synchrotron Radiation Workshop (SRW) simulation:

input \(\sigma_y = 10 \mu m\)

\[
K = 1, \quad \sigma_y = 10.0 \mu m \quad \gamma = 0.981
\]

\[
K = 4, \quad \gamma = 0.991
\]

Experimental Investigation

Use of commercial neutral density filters:

• 2mm glass substrate
• one half covered by black dots

→ dot density determines Optical Density (OD)

Two filters with OD = 0.38 and 0.95 were used

Two-Dimensional Interferometry

Difference: number of pinholes.

One-dimensional

Two-dimensional

First realization (Spring-8, Japan):


Example: pinhole 2 completely covered such that no radiation passes through \(\rightarrow\) imbalance in both directions

\[
K_x = (I_1 + I_2)(I_1 + I_2), \quad K_y = (I_1 + I_2)(I_1 + I_2) = 2
\]

SRW simulation: input \(\sigma_y = 10 \mu m, \sigma_x = 174 \mu m\)

Example: if one of the pinholes is closed, an asymmetry in the interference picture is introduced \(\rightarrow\) interference between pinholes 2 and 4 vanishes

Horizontal fit formula for the case when one pinhole covered is given as:

\[
I(x) = I_0 \left( 1 + \frac{1}{\gamma^2} \right) \left[ 1 + \left( \frac{x}{\gamma \lambda_0 R} \right)^2 \right]^{1/2}
\]

Vertical beam size measurement with OD ≈ 0.95 filter

Measured beam sizes are about a factor of 5 (OD = 0.39) resp. 3 (OD = 0.95) larger than the expected ones in the order of \(\sigma_x = 10 - 15 \mu m\).

First measurements with the 2-D imbalanced setup in both transverse planes are underway

Summary and Outlook

The present report summarizes first theoretical and experimental investigations of an intensity imbalance technique applied to a 2-D interferometer. The results indicate that the interference technique should be investigated more carefully using filters based on homogeneous attenuation, and that the extraction of beam size information from measured interferograms will not be possible using common interferometric formulas. The effective visibility depends not only on the visibility in the plane under investigation, but also on the “diagonal” one. In this situation, it is not possible to extract beam sizes from a single 1-D fit of the central cut of a 2-D interferogram, a full 2-D fit seems to be better suited.