Performance and optimization of X-ray grating interferometry

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Abstract

A theoretical description of the performance of a Talbot and Talbot-Lau type interferometers is developed, providing a framework for the optimization of the geometry for monochromatic and polychromatic beams. Analytical formulas for the smallest detectable refraction angle and the visibility of the setup are derived. The polychromatic visibility of the interference fringes is particularly relevant for the design of setups with conventional X-ray tubes, and it is described in terms of the spectrum of the source and the type of beam-splitter grating.

1 Methods

Grating interferometry (figure 1) is an imaging technique yielding complementary signals from the interaction of X-rays with matter. Besides the absorption image, a phase shift [1, 2] and a scattering [3] signal can be simultaneously retrieved from the interference pattern.

This approach does not rely on a highly coherent source, thus it can be applied to ordinary X-ray sources and not only to synchrotron facilities.

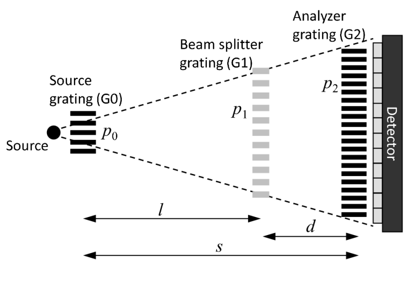

Figure 1: Parameters of a grating interferometer. The Talbot interferometer does not include a source grating G0.

In order to achieve maximum performance, the design parameters of the interferometer, such as the pitch of the gratings and their position have to be tuned. Analytical formulas for a the smallest detectable refraction angle and visibility are derived.

2 New results

The minimization of the smallest detectable refraction angle $\alpha_{\min}$[4] for a Talbot intereferometer is achieved in two steps. The smallest source sizes w and analyser grating periods should be chosen, according to the properties of the X-ray tube and the available grating technology. Then, an optimum period p_{11} of the beam-splitter grating can be calculated as shown in figure 2.

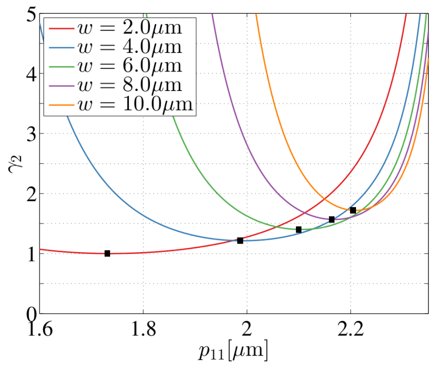

Figure 2: Optimization of a Talbot interferometer. The quantity γ_2 is proportional to the smallest detectable refraction angle and it is shown that there is a minimum for different source sizes w and for $p_2 = 2.4\,\mu\text{m}$. The minima are the black markers.

For the Talbot-Lau design, the smallest $\alpha_{\min}$ is achieved for the smallest sum of the pitches of G0 and G2, and is therefore limited by the grating fabrication.

The duty cycle κ of the absorption grating also affects the sensitivity of the system, and it can be shown that, for an ideal grating, the optimum duty cycle is $\kappa = 0.371$ in both configurations.

The dependence of the fringe visibility on the photon energy is derived. The spectral acceptance of the interferometer can then be analyzed as in figure 3. The numerical calculations show the visibility for a point source with a gaussian spectrum at various Talbot orders and prove that π-shifting phase gratings give better results than $\pi/2$ shifting gratings, except for the first Talbot order, where they are substantially equivalent.

The results of these theoretical calculations have been used in the design of a Talbot-Lau interferometer for a high-energy X-ray tube (160 kVp) at the Paul Scherrer Institute (Switzerland). An analysis of the performance and the first experimental results will be presented.

3 Submissions

Part of the theoretical aspects in the present work are being submitted to Phil. Trans. A. Additionally, the presentation includes the experimental results from a new interferometer designed according to these guidelines.

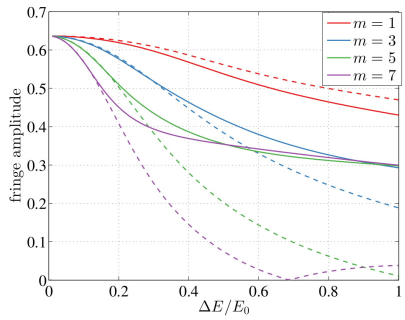

Figure 3: Fringe visibility for a polychromatic beam of a point source as a function of the normalized energy bandwidth $\Delta E/E_0$ of a gaussian spectrum for different talbot orders m and for $\eta = 1$ (dashed lines) corresponding to a $\pi/2$ shift in the phase grating structures, compared to a π-shifting phase grating (solid lines).

References

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