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Effect of spatial coherence on application of in-line phase contrast imaging to synchrotron radiation mammography

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Abstract

Effect of spatial coherence on the application of in-line phase contrast imaging (IL-PCI) to synchrotron radiation (SR) mammography is investigated experimentally at SYRMEP/ELETTRA. Factors that are related to spatial coherence and IL-PCI image quality, which include vertical and horizontal beam, photon energy, slit width, sample–detector distance and detector resolution, are analyzed. The experimental results demonstrate that better IL-PCI image quality could be achieved in the vertical beam. As for the slit width, the spatial coherence for horizontal beam remains almost the same until the slit width is gradually closed to 5 mm. For mammography applications of IL-PCI, slit width of 100 mm could be employed and high-enough image quality can still be obtained. Lower photon energy results in better coherence and correspondingly better IL-PCI image quality. By compromising the dose and image quality, photon energy of ~19 keV is recommended for SR mammography. To preserve the edge enhancement resulting from good coherence of SR, an appropriate sample–detector distance and a practical detector should be selected. The optimum sample–detector distance highly depends on detector resolution. For high-resolution film, the best IL-PCI imaging quality is obtained at a closer sample–detector distance. For an X-ray CCD with pixel size of 14 μm, about 1.5 m is needed to achieve optimum image quality. The large pixel size of the detector will deteriorate the edge-enhancing efficiency and results in lower IL-PCI imaging quality. In practice, the spatial resolution and sensitivity of the detectors should be compromised.

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Keywords: Spatial coherence; Phase contrast imaging; Mammography; Synchrotron radiation

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1. Introduction

Up to now, applications of in-line X-ray phase contrast imaging (IL-XPCI) to medical physics, biology, material science and chemical dynamics, etc., have been reported [1–4]. As for mammography with IL-PCI, some pioneering experiments with synchrotron radiation (SR) [5,6] have been reported. With the monochromatic X-ray from SR, it is possible to obtain a mammographic image with low dose [6]. At present, X-ray tube is considered to be the most promising source for clinical application of XPCI-mammography and some R&D research work have been done by different groups [7–9]. Developing a practical source is the main problem encountered. Up to now, SR with high flux and high brightness will still be a good candidate for the investigations on XPCI-mammography.

Due to the characteristics of SR, only a very flat beam is emitted (for SYRMEP's case, the size is 100 mm × 3 mm). So we have to scan the sample to achieve a large field of view. Another solution is to employ the asymmetric Bragg reflection to expand the SR X-rays for the purpose of imaging samples with large size.

In IL-PCI, the requirement on X-ray coherence is moderate, compared to X-ray interference and holography. For temporal coherence, $\Delta\lambda \sim \lambda_0$ will not reduce the contrast too much according to the analysis of OTF [2]. It is even possible to record a phase contrast image with an in-line setup using multichromatic X-ray beam. Usually, X-ray beam with good-enough spatial coherence is essential to IL-PCI. In this paper, effect of spatial coherence on application of IL-PCI to SR mammography will be investigated experimentally.

2. Spatial coherence at SYRMEP beamline

First of all, the spatial coherence of X-ray beam from SYRMEP/ELETTRA will be analyzed.

The setup for light propagation from a finite source is shown in Fig. 1. According to diffraction theory, dimension of the Airy disc at a distance L from the source is $D_A = \lambda L/D_s$, where λ is the wavelength, D_s is the source size. When the dimension of the interested area D_c at the observing plane is less than Airy disc, $D_c < D_A$, it is impossible to identify which point of the source the light comes from. This means that the light in this area is spatially coherent and we have spatial coherence width (SCW):

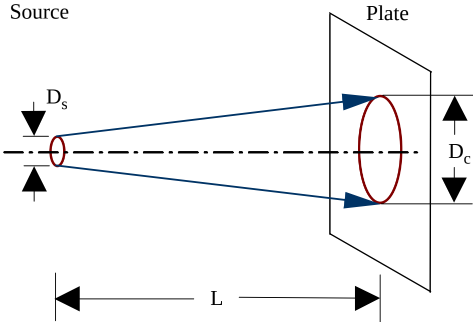

Fig. 1. Setup for light propagation from a finite source to a plate.

$$D_c < \lambda L/D_s. \quad (1)$$

Also, we have

$$D_s D_c/L < \lambda. \quad (2)$$

From this formula, we know that the spatial coherence depends on the product of source size and open angle of the interested area to the source and the wavelength of light. More details about formula (2) are discussed in the following. Keep D_s and λ constant, SCW can be improved by increasing the distance L between the source and observing plate. As regards the source size, the smaller the D_s, the better the spatial coherence. Also, it is obvious that for larger wavelength we can get good coherence more easily. For synchrotron source, value of $D_s D_c/L$ is actually the emittance. Natural emittance for ELETTRA is 7 nm rad. This implies that light with wavelength larger than 7 nm is spatially coherent. At SYRMEP beamline, the sample stage is 26 m from the source. For the source size, usually 4σ is used, then we have $D_{sh} = 0.54$ mm, $D_{sv} = 0.32$ mm. For the photon energy of 17 keV, SCW value should be

$$D_{ch} = 3.5\,\mu\text{m},$$

$$D_{cv} = 5.9\,\mu\text{m}$$