DEVELOPMENT OF SPECKLE BASED X-RAY IMAGING

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Summary: Phase Contrast Imaging takes advantage of the dual properties of the X-rays to reveal sample enhanced details in many domains. The work presented herein aimed at evaluating the sensitivity of a new acquisition technique called Speckle Based Imaging. The study also provides comparisons of quantitative aspects between Speckle Based Imaging and Propagation Based Imaging.

1. INTRODUCTION

With their inherent advantages, synchrotron light sources gave birth over the last two decades to a few high performance 3D imaging modalities that now now are applied in a routine fashion to various type of samples bringing new scientific insights. Phase Contrast based Imaging (PCI) is one particularly interesting approach that exploits the dual properties of X-rays that translate into both absorption and refraction of the beam when it passes through matter. The interaction law of X-rays with matter is usually described with the complex index of refraction of the medium: $n = 1 - \delta + i\beta$ where δ is the refraction part and β the absorption factor. The δ index can be a thousand times greater than its counterpart β for light elements making PCI valuable for the imaging of low absorbing samples (1).

In the last years, PCI showed its potential in a wide range of domains such as cultural science, medicine or material engineering. Amidst the main currently available PCI approaches are Propagation Based Imaging (PBI), Grating Interferometry (GI), Analyzer Based Imaging (ABI) and Edge Illumination (EI). These techniques employ various principles and then present different advantages and limitations. For instance, in spite of being today the widest spread phase-contrast modality at synchrotrons, PBI presents the main drawback of requiring large transverse coherence lengths. Besides, the method principle is sensitive to the phase Laplacian of the beam which can introduce reconstruction artefacts when imaging an object with a slowly varying density or low spatial frequency features. In practice, a phase gradient sensitive method such as GI, ABI or EI would be preferable to image such kind of homogenous samples. Near field Speckle Based Imaging (SBI) is an innovative X-ray phase gradient sensitive method falling into that method category and whose interest from the community is growing due to its easiness of implementation and the possibility to take it outside synchrotron sources(2)(3). SBI already demonstrated a great sensitivity using moderate energy X-rays for the characterization of slowly varying material densities. However, up to now, no experiment demonstrated the capacities of SBI for quantitative high energy X-ray imaging, which is required for the depiction of electronically dense (high-Z material) or thick samples.

In this context, our work aimed at evaluating SBI's sensitivity for polymeric material discrimination and accurate characterization of large composite samples (glass or carbon fibers in polymer matrix). Experimental examples illustrate the potential of SBI different modalities when working at high energy. The use of various phantoms and reference composite materials allowed comparisons of quantitative aspects between SBI and PBI.

2. EXPERIMENTAL METHOD

These experiments were conducted at the European Synchrotron Radiation Facility (ESRF), Grenoble, France. Experimental configurations based on monochromators and filters provided mono or pseudo-monochromatic beams with photon energy above 60 keV. The detectors used were CMOS and CCD based cameras coupled to optics which image scintillators converting the X-ray to visible light by luminescence. The effective pixel sizes of these systems were ranging from 15 to 50 μm. The use of a dedicated tomography stage allowed a stable and accurate rotation of a samples during which several thousands of images were collected. The long beamline hutches permitted to use propagation distances up to 11 meters between the sample and the detector. For the SBI implementation, a phase object located close to the sample as presented in figure 1, modulated the wavefront in intensity. Such speckle generator has to contain features with random high spatial frequencies. In this endeavor, various scattering objects such as sandpaper, steel wool or glass mesh were used to generate the intensity wavefront modulation by interferences of the synchrotron beam. The imaging of phantoms enabled the quantitative analysis of the modality signals. Various resolution modules filled with nylon fibers of different diameters and of solutions of known concentrations composed the phantoms. The method sensitivity was evaluated by computing signal-to-noise ratio. The calculation of the point spread functions of our imaging system provides an estimation of the spatial resolution.

Phase contrast based imaging necessitates a retrieval algorithm to access the refraction induced by a sample on a partially coherent X-ray beam. The algorithm employed for PBI required an a priori assumption on the materials' complex refractive index, whose values were taken from the ICRU 44 database. For SBI, phase, absorption and dark field signals were extracted following the method of (4). The filtered back projection CT algorithm permitted then the reconstruction of the 3D sample material distribution from the previously calculated phase images. More specifically, the CT reconstructions used an open-source, Graphics Processing Unit (GPU)-based implementation of the PyHST2 code(5).

3. RESULTS AND CONCLUSION

The SBI approach allowed phase, dark field and absorption signal recovery while PBI provides access only to the phase and absorption signals. Our experiments demonstrated that SBI have enhanced SNR and CNR values thereby improving the method material discrimination ability. Moreover SBI does not requires any a priori assumption on the sample composition by contrast with PBI. In addition, the availability of dark field contrast enables access to new information, which can eventually help for the characterization of composite materials. On the other hand, SBI still necessitates a longer data acquisition time than PBI although ways of reducing these requirements are under study.

This work presented the first quantitative results using X-ray SBI at high energy. These indicate that SBI, with a simple setup, show high potential for the 3D elemental mapping of thick or dense samples. Further works will focus on the robustness toward noisy data, the optimization of the data acquisition time and the method compatibility with lower brilliance X-ray sources such as the ones found in laboratories. Another orientation of investigation regards the combination of the method with newly emerging coherent sources such as laser-plasma and Compton back scattering based ones. Such adaptation to much more compact and accessible sources would greatly broaden the approach potential fields of application.

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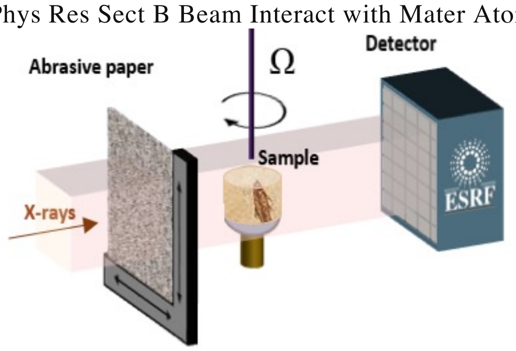

Figure 1: Setup used for speckle based imaging methods.