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COMMUNICATIONS

EXPERIENCE WITH IMAGING BY USING OF MICROFOCUS X–RAY SOURCE

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In this paper we present the current work and experience with using microfocus x-ray generator and commercial CCD camera for x- ray imaging purpose. There is a need in laboratories for the development of imaging methods approaching synchrotron radiation sources, where the brilliance of radiation is on very high-level. Generally, there is no continuous access to synchrotron facilities. Several synchrotron radiation laboratories allocate the access via a proposal system. Thus the time for synchrotron radiation experiments seldom exceeds more than 1-2 weeks per year, which restricts its application to a few selected experiments. Even in future, the routine characterization of samples will be performed mainly at the experimenters home laboratories [10]. In this contribution we show that with the present set-up it is possible to achieve the spatial resolution down to μm and with the appropriate geometry a phase contrast images are observable.

K e y w o r d s: x-ray imaging, x-ray imaging system, parameters of the x-ray imaging system

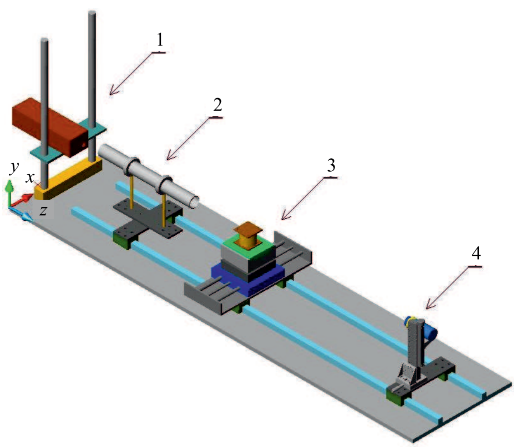

Fig. 1. Experimental setup (1) Hamamatsu microfocus, x-ray source (L6731-01 type), (2) Collimator ⌀50 × 500 mm (option), (3) Newport goniometer to adjust and rotate the object or optics (resolution 0.0002°), (4) x-ray Mini FDI camera, Photonic Science with pixel resolution: 1392 × 1040 (4:3 aspect ratio), input pixel size: 6.4 μm^2, input active area: 10 × 8 mm, Scintillator: gadolinium oxysulphide doped with terbium and energy response: optimum 5 keV to 17 keV [9].

1 INTRODUCTION

Recent developments of the x-ray imaging techniques at synchrotrons such as phase contrast imaging [1, 2] present a strong driving force for the development of laboratory x-ray imaging techniques [3]. The brilliance of new micro-focus sources combined with suitable source-side optics gives the possibility to transfer some demanding experiments from synchrotrons to laboratories. Concerning the detection side, new approaches include single photon counting with semiconductor radiation detectors and the so called "colour imaging allowing evaluation in a preselected photon energy window [4]. These new techniques substantially improve the overall diagnostic performance of new generation x-ray systems [5].

2 EXPERIMENTAL SETUP

Based on our experience in x-ray crystal optics, semiconductor detectors and x-ray imaging, we are developing a variable x-ray optical bench to study some of these modern imaging techniques [5].The enclosed radiation leak protected optical bench 2.6 m long contains a vertical stand for a Hamamatsu microfocus x-ray source (L6731-01 type) with declared focus size 8 μm, target voltage: 20–80 kV, target current: 0-100 μA, minimum distance focus-object: 12 mm, beam angle: 39°, environmental x-ray dose leakage: 5×10^{-3} mSv/h max, longitudinal slides for changing geometrical magnification and moving various components, a Newport goniometer to adjust and rotate the object or optics, and another stand for detector or camera slides [6, 8].

3 THEORY

The first results have been obtained by using the technique of free-space propagation imaging.

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Fig. 2. The enclosed radiation leak protected bench top x-ray imaging system

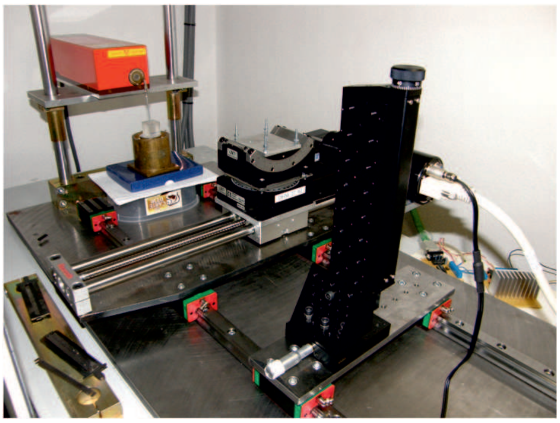

Fig. 3. Interior of the x-ray imaging system with x-ray source (red box), Newport goniometer in the middle and CCD camera the black stand in the right of the picture

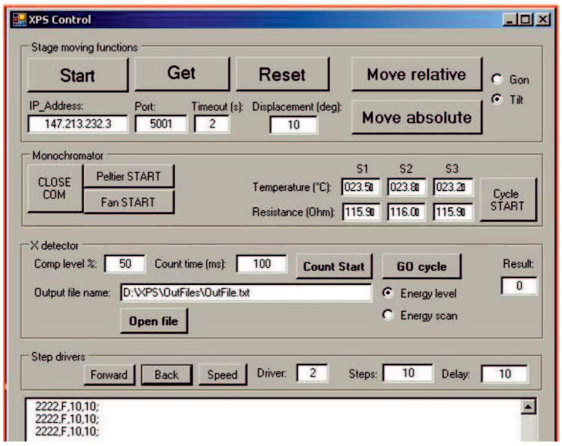

Fig. 4. The self developed software screen for control of several function like goniometer, tilt, monochromator, x-ray detector, stepper motor, which can be extended to other required functions

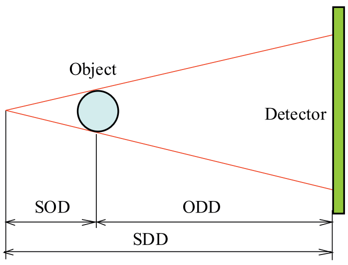

Fig. 5. Geometry of the so called Free Space Propagation Imaging. SOD-Source Object Distance, ODD-Object Detector Distance, SDD-Source Detector Distance

In order to achieve phase-contrast imaging, the x-ray tube must provide a sufficient degree of spatial or lateral coherence which is given by

$$d = [\lambda(\mathrm{SOD})]/f\,, \tag{1}$$

where λ is the wavelength, SOD is distance between the source and the object an f is the focal spot size of the tube. The magnification that occurs at a distance ODD is given by the relation

$$M = (\mathrm{SOD} + \mathrm{ODD})/\mathrm{SOD} = \mathrm{SDD}/\mathrm{SOD}, \tag{2}$$

The image contrast obtained from the x-ray intensity profiles of an object is provided by the relation

$$Contrast = (I_{max} - I_{min})/(I_{max} + I_{min})\,, \tag{3}$$

Another parameter that can be calculated in the image is the penumbra arising form the finite size of the focal spot in the magnification images. From simple geometry, the geometrical unsharpness is

$$U_g = f(\mathrm{SDD}/\mathrm{SOD})\,. \tag{4}$$

Where SDD is the distance between the source and the object, SOD is the distance between the object and the detector and f is the focal spot size [2].

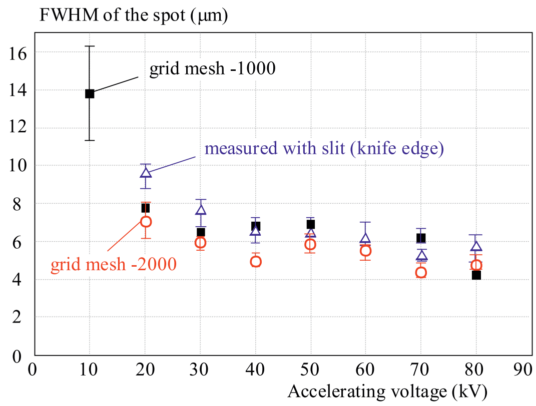

Fig. 6. Dependence of the spot FWHM on the accelerating voltage

3 RESULTS

Testing of focus size of x-ray source

The focus size of the x-ray source with a transmission tungsten anode (declared as of 8 μm) has been measured using the technique of imaging a tungsten crossed wires according to EN 12543-3 [7]. At the full power of 80 kV and 100 μA the technique has given focus size of 8.6 μm in horizontal and 6.2 μm in vertical direction [5].

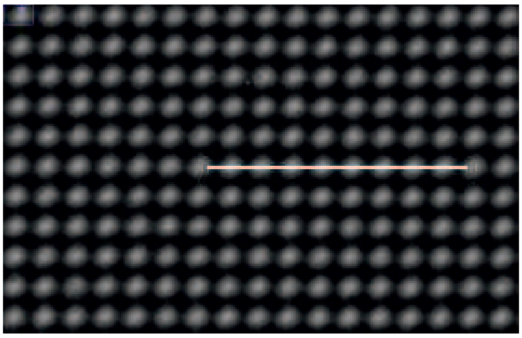

Fig. 7. x-ray image of a gold microscopic grid with 4 to 5 μm stripes, 12.5 μm period taken with the geometrical magnification of 9.1, accelerating voltage 40 kV, current 100 μA, exposure time 10 s

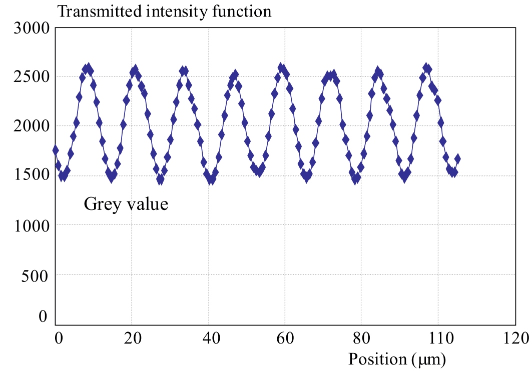

Fig. 8. Transmitted intensity function from the white horizontal region indicated in Fig. 7

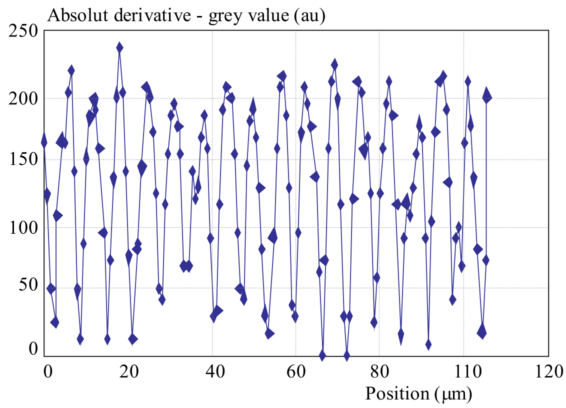

Fig. 9. Absolute value of the first derivative of the transmitted intensity profile and calculated FWHM of 3–5.2 μm

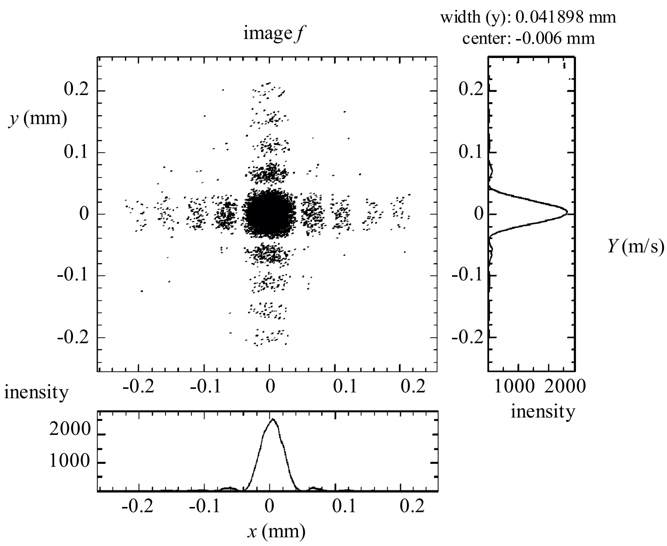

Fig. 10. Fraunhofer diffraction at a rectangular slit as simulated by the ray-tracing program RAY

Dependence of x-ray tube focus size (FWHM) on tube voltage

The measurements were performed with three tools: grid mesh-1000, grid mesh-2000 and a slit, edges of which were used as "knife edges. Though differences are larger than estimated error bars, the results seem to be consistent between the three sets.

Measurement of spatial resolution

One of the most important imaging parameters is spatial resolution. A technique using the full width at half maximum (FWHM) of the absolute derivative of the transmission function of a gold grid has been used for the purpose. The distance between the source and the sample was 27 mm and the distance between sample and camera 219 mm, while the magnification was 9.1.

Simulation of Fraunhofer diffraction

To assess the coherence character of imaging, we are simulating the Fraunhofer diffraction at a rectangular aperture using the BESSY ray-tracing program RAY [9]. Preliminary results show that ripples up to 100 μm distance from the edges are observable (see Fig. 10), confirming beam coherence. The simulation parameters: number of rays: 10 000 000, source: (w × h × d) = 0.008 × 0.008 × 0.008 μm, photons energy: E0 = 8039.960 eV, ($\lambda = 0.1542\,\mu$m), ΔE = 4000–12000 eV. One optical element: slit (w×h) = 0.001×0.001 mm, source-slit distance: 32 mm, slit-image plane distance: 290.8 mm.

The first images done with the built-up imaging system

a) $M = 1.02$, SDD = 508.8 mm, SOD = 500 mm b) $M = 2.29$, SDD = 370.8 mm, SOD = 162 mm c) $M = 9.09$ SDD = 290.8 mm, SOD = 32 mm 80 kV, current 100 μA, exposure time 20 s. a) the absorption contrast is dominating, b) phase contrast is starting to be seen, c) phase contrast is quite good observable, brightness on the edges (minimum of intensity profile) due to the tilt of the beam in place with the change of the refractive index. M — geometrical magnification (M = SDD/SOD), SDD — source-detector distance, SOD — source-object distance.

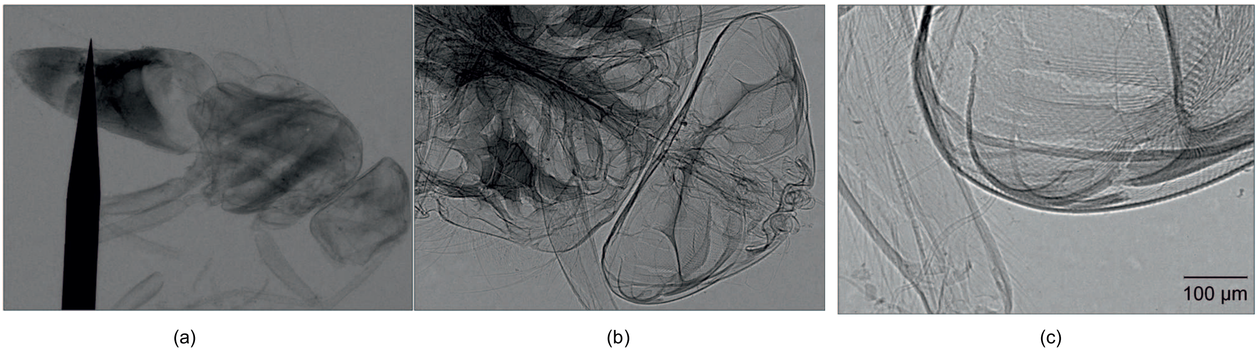

Fig. 11. The first images done with the built-up imaging system: (a) – M=1.02 SDD = 508.8 mm SOD = 500 mm, (b)– M=2.29 SDD = 370.8 mm SOD = 162 mm, (c) – M=9.09 SDD = 290.8 mm SOD = 32 mm

5 CONCLUSION

Basic parameters and options of the current set-up of the imaging system were defined. The first experience shows that with the present set-up it is possible to achieve the spatial resolution down to $3\,\mu$m. The system in this establishment is suitable for small samples, because of using a camera with a relatively small input active area approximately $10\,\text{mm} \times 8\,\text{mm}$. The high resolution rotation stage for the sample holder allowed us to take sequential computer tomography pictures which are now being reconstructed into 3D tomographs.

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