

COMPUTERIZED TOMOGRAPHY USING HIGH RESOLUTION X-RAY IMAGING SYSTEM WITH A MICROFOCUS SOURCE

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1. Introduction

In recent years there is an effort to image an internal structure of an object by using not only conventional 2D X-ray radiography but also using high resolution 3D tomography which is based on reconstruction of multiple 2D projections at various angular positions of the object. We have previously reported [1] the development and basic parameters of a high resolution x-ray imaging system with a microfocus source. We report the recent progress using this high resolution X-ray laboratory system in this work.

2. Computerized Tomography and software

In X-ray Computerized Tomography (XCT) a series of radiographs are collected at different viewing angles. This set of radiographs, called projection data, is processed with a reconstruction algorithm to generate the tomogram of the specimen. Tomogram is a three dimensional representation of the specimen structure. The smallest three dimensional unit in the tomogram is called voxel. The projection data are collected within cone beam geometry through a full 360° rotation of the sample. The optimal number of projections is given by $N_{\theta} = (\pi/2)N_W$, where N_W is the number of pixels in the horizontal line of the detector. This number ensures that there is adequate angular sampling to accurately reconstruct the specimen [2].

An important prerequisite for high resolution XCT is high spatial resolution of the 2D projections which is possible by using an optical magnification of the object. With the present set-up it is possible to achieve the spatial resolution of the whole X-ray imaging system down

to 3 μm [1]. There is a possibility to express the so-called CT voxel size as the ratio of CCD pixel size and a magnification factor of the imaging setup. Our imaging system with microfocus X-ray source allows a magnification factor of 140. For example imaging distance required to obtain an image magnified 40 times is 480 mm because of shorter focal length (12 mm) compared to conventional type of X-ray source. Moving a CCD camera on linear bearings to obtain magnification between 1.1 to over 140 allows to regulate the voxel size between 5.8 μm and 0.05 μm . X-rays emitted from the finite source show a blur aberration, which destroys the volume resolution significantly above the minimal voxel size of tomograms. At magnification factor of 140 the lateral coherence lengths of the X-ray tungsten energy spectrum are in the range from 0.3 μm to 13 μm . This property of X-rays allows an increasing visibility (contrast) of some features of the object by means of the so-called phase contrast.

Processing of large data sets necessary to reconstruct three dimensional high quality images of samples imposes high computational demands. For the processing of tomography data or in other words generating data set of tomograms we use Octopus reconstruction package. The Octopus reconstruction package was initially developed for the reconstruction of parallel beam neutron tomography data, and has since evolved to one of the most versatile and performing packages for the processing of tomography data acquired in almost any geometry [3]. This software works with graphics processing unit (GPU). In our case, GPU consists of 448 stream processors (CUDA cores). The acceleration of reconstruction process has reached up to ten times in cooperation with the quad-core processors compared with CPU computing.

3. Experimental setup

A Newport high resolution rotation stage (minimal incremental motion = 0.0002°) for the sample holder will allow to take sequential computer tomography (CT) projections. We use a CCD X-ray mini FDI camera (Photonic Science) as a detector. Basic parameters of the camera are: pixel resolution: 1392x1040, input pixel size: 6.4x6.4 [μm], active area: 10x8 [mm], scintillator: $\text{Gd}_2\text{O}_2\text{S:Tb}_3$, with optimal energy response from 5 keV to 17 keV. The focus size of the X-ray source with a transmission tungsten anode is declared as of 8 μm and the source emits 39° conical beam. All system components are installed in an enclosed radiation leak protected, 2.6 m long optical bench with rubber shock absorbers between legs and ground.

4. Results

Several samples of various density and composition were used to evaluate imaging properties of presented experimental set-up for 3D tomography. The obtained results show that the light-weight materials are not so prone to artifacts in final tomograms. Fig. 1 shows one of 720 projections of fly's head with magnification factor of 2.5. Reconstruction of the object was done by means of Octopus software and object's surface was visualized by AVIZO software <http://www.vsg3d.com/node/25> (see Fig. 2). The effect of phase contrast, occurring at the object edges in the 2D projections did not have observable influence on the image quality in final 3D reconstruction volume.

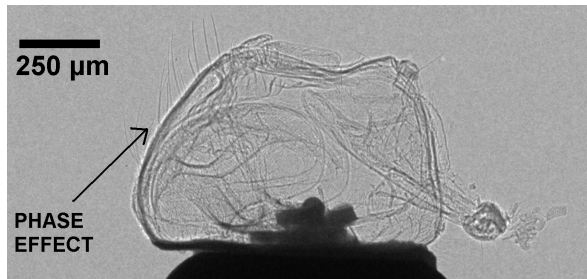


Fig. 1: *Projection of fly's head.*

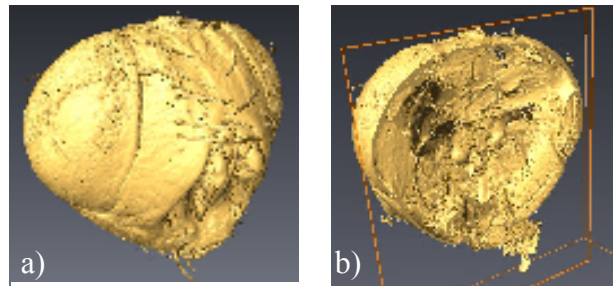


Fig. 2: *a) Reconstruction of the surface, b) cross-section through the sample.*

Lower energy x-rays passing through a sample are more absorbed than higher energy x-rays and the polychromatic x-ray beam becomes harder. The effect is called beam hardening. This phenomenon causes in reconstructed slices the so-called cupping effect. Fig. 3a) shows a slice of aluminum-copper alloy sample and Fig. 3b) corresponding cupping profile. Beam hardening phenomenon causes non-linear detector element response and it is one of several causes of the appearance of ring artifacts [4]. The presence of such artifacts complicates quantitative analysis and post processing such as noise reduction or voxel segmentation.

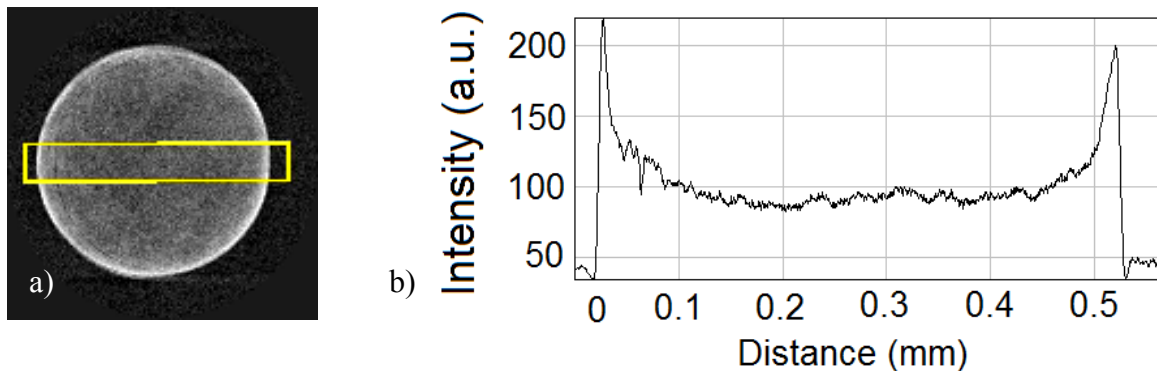


Fig. 3: *a) Reconstructed tomography slice of an AlCu alloy. b) Intensity file yellow horizontal region indicated in a) shows cupping shape with the sharp peaks on the edges of the profile.*

5. Discussion and conclusion

Visibility of some features of the first biological object in Fig. 1, is caused by emphasizing edges due to the phase effect. Reconstruction algorithm in Octopus software is based on X-ray absorption tomography, where projections are formed by measuring the attenuation of radiation that passes through a physical specimen at different angles. It could be assumed that phase effect due to the tilt of the beam in place with the change of the refractive index may generate artifacts in reconstructed volume. Fig. 2 shows no edge artifacts and the final result is quite good. In the second case a non-biological object made of Al-Cu alloy was reconstructed by using the Octopus software, too. It showed much larger quantity of artifacts than in the first case. These artifacts complicate voxel segmentation in post processing by 3D visualization. Although 2D visualization of individual slices was sufficient, it was difficult to get an idea of the spatial distribution of the denser regions at voxel segmentation (see the darker areas in the section in Fig. 3).

These first findings show that our system is particularly suitable for light weight and nonmetallic objects such as biological objects, plastics, wood, paper, etc. where phase contrast helps to increase the visibility of the finest structures of the object. Phase-contrast X-ray Computerized Tomography is of our special interest because it is an emerging imaging technique that can be implemented at third generation synchrotron radiation sources and also in laboratory conditions using a microfocus X-ray tube or beam conditioning optics.

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