Setups for Tomographic Imaging with Submillimeter Spatial Resolution

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Abstract. In the work development of setups for tomographic visualization is presented. Detectors with resolution better than 1 mm were used. As a result of the work sinograms were obtained. These results can be used for medical purposes.

In spite of wide spreading X-ray methods for study inner structure of objects, X-ray technologies are still developing actively. It is driven by advances in computer science that allow using more sophisticated software and hardware to obtain more precise and reliable results. From the other side, researchers pay more and more attention to visualization of inner structure of objects. These factors lead to high urgency of the problem.

In this paper we present results of research on developing prototypes of X-ray setups that were used to obtain both two-dimensional shadow projection images and tomograms. A tomogram or a planar slice is a common way for studying internal structure of objects and it is a base for 3-D tomography and volume visualization. The goal of the developing prototypes is applying obtained results in medicine. In fact, X-ray tomography has made a great advance since its invention. However, dose rate decreasing in medical applications is still an urgent issue. In this paper we present results which can help to solve the dose rate decreasing problem.

In the work two X-ray prototypes were created. Pulsed X-ray tube was used as radiation source in these prototypes. Different linear detectors were chosen for different prototypes.

In the first prototype strip semiconducting GaAs detector was applied. It was chosen due to its high spatial resolution, good sensitivity and response speed.

In the second prototype multichannel linear gas-discharged detector was used. Detectors of this type have low spatial resolution compare to this of semiconducting ones. However, they are effective-cost solutions and have a large sensitive area which make them useful devices in some applications.

We used pulsed X-ray tube RAP-160-5 as radiation source. Focus spot for this tube is 1.2 mm × 1.2 mm. Power with the peak parameter is 0.6 kW. Accelerating voltage could be changing in the range from 40 to 160 kV. Values of anode current are changing from 0.4 to 5 mA. All parameters are given as integral ones due to pulse mode of X-ray tube. Frequency of pulses could be changed automatically from 60 to 700 Hz. The frequency depends on value of required current. Pulse duration is about 140 μs. The tube can be synchronized with external devices by the dedicated output [1].

Solid-state strip detector GaAs 512-0.1 was used for prototype based on semiconductor detector line. Period of line generation could be set by inner or external sync signal with duration not less than 140 μs. This is connected with procedures needed for inner processing of a cycle. The device has function of choosing time for dose acquiring. Resolution of the detector is 5 LP/mm. Width of sensitive area is 51.2 mm.
Digital linear multichannel gas-discharge detector PRIZ-1536 was used in the second prototype. Detecting plate consists of 1536 signal strips with pitch 250 μm. Width of sensitive area is 384 mm. Time of signal integrating is 2.5 msec. PRIZ-1536 can also operate with inner and external sync signal. Detecting part is arranged on a special designed mechanism, which allows to set the detecting part automatically on the translation arc with path 400 mm [2].

In the first prototype setup with GaAs line detector, both the X-ray source and the detector stay motionless on the same line while the scanned object rotates and moves to the right or to the left during the data acquisition. In the second setup, the X-ray source and the object stay on the same line while the gas-discharge detector moves to the right or to the left on its translation stage. Both setups produce continues series of line shadow projections also known as sinograms.

Synogram is a visual representation of stacked projections acquired from a layer of the object at different angles. The method used for obtaining lines of synogram image and principle of stacking lines into sinogram are shown on figure 1.

The X-ray source, the scanned object and a detector are placed on the same line to obtain a single line projection. The object rotates by some definite angle step on the axis perpendicular to the “source-detector” line. Thus, shadow projections of the object on different angle positions are registered by detector. Typically, the object makes a complete revolution, 360 degrees, to produce a single sinogram. The GaAs line detector setup employs the slightly divergence beam geometry with angles not exceed 5 degrees and can be treated as pseudo-parallel, while the second one uses the fan beam geometry and should be processed properly.

Resolution of reconstructed image depends on intervals of object’s rotation angle (the smaller interval the better resolution). However, there are number of disadvantages because of decreasing interval of angles. Firstly, the number of images increases with increasing number of angular projections, and consequently dose loading of the investigated object increases. Secondly, size of differential equation system, formed during reconstruction, depend on number of detectors and projections.

Computing software MATLAB was used for reconstruction of tomographic slices from sinograms in case of parallel beam of X-ray. We used function “iradon” from MATLAB’s addon Image Processing Toolbox [3] for the Radon transform.

There are a number of difficulties with using divergent beam of X-ray in design of algorithm for reconstruction from sinogram was. There is function “ifanbeam” in MATLAB software for inverse Radon transform in the case of divergent beam. A number of restrictions for input parameters in the function “ifanbeam” make impossible using this function for achieving our goals [4]. We decided to use software NRecon designed by company Bruker micro-CT (former Skyscan) [5] for reconstruction
of slice in case of divergent beam. There are no restrictions for geometry of a beam, intervals of an angle and total angle of scanning.

Series of projection images and sinograms of different objects were obtained using these prototypes.

The example of shadow projection image produced by the GaAs line detector setup is presented on figure 2. The object is a bar made of Pinus sylvestris 50×50×20 mm in size with a screw and a fastener in its body.

![Figure 2. X-ray projection image of pine bar with screw and fastener system.](image)

The image has a number of defects which are typical for digital detection systems. Linear artifacts caused by poor calibration are clearly seen. Different sensitivity of detectors on the intermediate intensity of signals (in range of the lowest and the highest digital accounts) prevented calibration of high quality. Moreover, there are several horizontal lines caused by bad detectors. It should be noticed that these issues are easily eliminated by software.

A sinogram of the wooden bar and its reconstructed slice (a tomogram) are presented on figure 3. The tomogram has pronounced ring artifacts due to difference in detectors sensitivity. However, the internal structure of the sample is easily revealed.

![Figure 3. A sinogram of the wooden bar and its tomogram.](image)

The defects described above define the artifacts arising during reconstruction of tomographic slice. The lines caused by a poor calibration of detectors will be transformed into ring artifacts on the sinogram. Nevertheless, the reconstructed tomographic slice allows identifying growth rings. Quality of growth rings on the tomographic slice allows defining thickness and the sizes of rings.
On figure 4 reconstructed tomographic slice of “Low Contrast insert” (the module of a tomographic phantom) is presented. The module is made from tissue-equivalent material. Diameter of the module is 203.2 mm [6].

![Figure 4. Reconstructed tomographic slice of “Low Contrast insert”.](image)

There are beam artifacts on figure 4 caused by opacity of a rod on which the module fastened. Fluctuations in registration of radiation by the multichannel gas-discharge detector and statistical nature of X-rays led to visible granularity. Fluctuations were caused by low level of registered radiation.

After obtaining images, the technique of a dose rate measurement during work with a pulse source was developed. Radiation monitoring with pulse sources have a number of difficulties. The RAP-160-5 tube emits only 2% during the working period. A current in a single impulse is high, approximately 50 times higher than integrated values. Besides, impulse frequency of the source is high and that requires using only high speed data-acquisition equipment.

In experiment solid-state thermoluminescent detectors were used. These dosimeters meet all requirements of a problem: working limits of dose rates and the absorbed doses correspond to measured modes [7]. Using the storage type detectors solves a problem with registration speed of a dose.

Dosimeters were irradiated in points of sample arrangement at the same modes, as at obtaining pictures. Dose rates were defined taking into account an exposition.

Using prototype with the semi-conductor detector for obtaining shadow projection images the equivalent dose was 14 µSv. Obtaining one sinogram on this installation resulted in the calculated equivalent dose 2.8 mSv.

The calculated equivalent dose was 15 µSv during obtaining shadow projection images using prototype with the gas-discharge detector. The calculated equivalent dose was 9.5 mSv for obtaining synograms.

These resulted doses are less than standard doses for medical film radiography. For example, for photofluorography the norm is considered 0.8 mSv, for radiography – 0.4 mSv, for radioscopy – 10 mSv [8].

Doses decreased mostly due to using pulse source in the described prototypes. Using synchronization between the pulse source and the detector excluded useless dose loading.

Unfortunately, application of low intensity radiation leads to decrease in quality of visualization. Contrast sensitivity decreases with using the gas-discharge detector. In addition, there are issues due to
nonlinearity of detectors sensitivity in case of the GaAs line detector. However, decreasing of dose rates is crucial in medical diagnostic, therefore the further studies should be made in order to achieve higher quality of visualization.

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