

# Modernization of the X-Ray Tomographic Scanner Based on Gas-Discharge Linear Detector

S G Stuchebrov<sup>1</sup>, A V Batranin<sup>2</sup> and I A Miloichikova<sup>3</sup>

<sup>1</sup> Senior Researcher, Tomsk Polytechnic University, Tomsk, Russia

<sup>2</sup> Junior Researcher, Tomsk Polytechnic University, Tomsk, Russia

<sup>3</sup> Engineer, Tomsk Polytechnic University, Tomsk, Russia

E-mail: [stuchebrov@tpu.ru](mailto:stuchebrov@tpu.ru)

**Abstract.** In this paper, we describe the modernization of the tomographic scanner based on multi-channel linear gas-discharge detector. We have changed the principle of acquisition the projection data, which allowed to receive a bulk three-dimensional tomographic data instead of single slices of the studied samples. Modified scanner has shown increasing contrast and spatial resolution of single slices. The volume of interest in studied objects has been significantly increased and are as high as 25 000 cubic cm, which is determined by 1536 pixels in high

## 1. Introduction

Nowadays, multi-channel gas-discharge X-ray detectors are almost superseded by semiconductor detectors, because of their advantages such as speed, large dynamic range, small size of achievable detection step and others. However, the potential of multi-channel gas-discharge detectors has not been exhausted. Most studies of internal structures of objects, including medical studies, do not require high spatial resolution, while test objects often are characterized by relatively large geometrical dimensions. Higher cost of semiconductor detectors limits their usage in radiography and tomography for studying large objects. Here, multi-channel gas-discharge X-ray systems seem to be the effective solution due to their lower costs and larger sensitive area.

In Tomsk Polytechnic University tomographic setup based on a multi-channel gas-discharge detector PRIZ 1536 was developed to study the imaging performance in biological and medical application [1]. Obtained results have shown the potential of this type of detectors. The setup demonstrated necessary spatial resolution on standard test objects, required for medical studies. We used a pulsed radiation source and the setup was operating in synchronization mode to coordinate the X-ray tube and the detector. The pulsed X-ray tube produces not sufficient dose rate to obtain required contrast resolution on the test object with tissue-equivalent density and 20 cm in diameter, which are typical to the human body [2]. Attempts to deliver the required dose rate in a few cycles of exposure did not lead to success, since the noise in the gas-discharge detector increased proportionally. To overcome this obstacle we replaced the pulsed X-ray source by continuous source with higher brightness. For this task industrial X-ray apparatus Comet MXR-451HP/11 [3] was chosen.

The first developed setup used fan beam scanning geometry which provides tomographic data in the form of sinogram. After reconstruction, we could obtain information of internal structure of an object in one tomographic slice. The scanning geometry was changed and then detector moved across



the cone beam providing full shadow projections. Thus, necessary data for volumetric reconstruction were acquired.

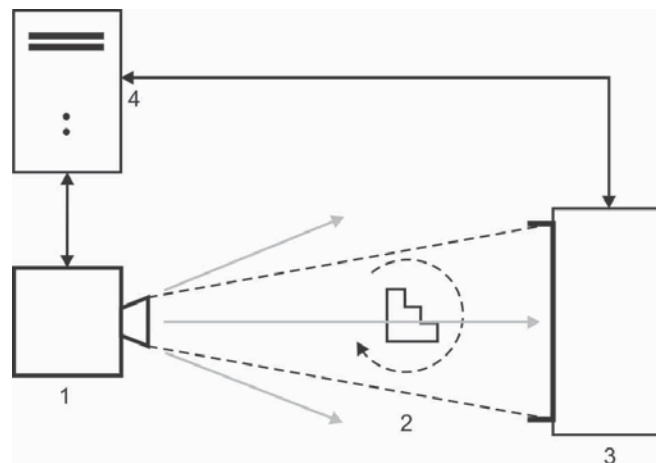
## 2. Materials and methods

### 2.1. Emitting source

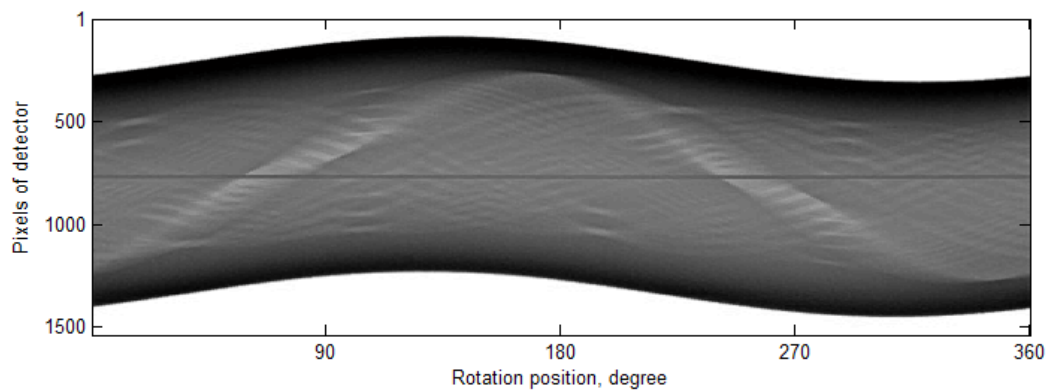
We used an industrial X-ray apparatus MXR-451HP/11 (manufactured by Comet Group, Switzerland). The source is equipped by bipolar oil-cooled tube with tungsten target and it has dual focal spot: 0.4 and 1.0 mm. Nominal tube voltage is 450 kV; the highest power is 500 or 1500 W depending on the focal spot size. Radiation coverage is  $40^{\circ} \times 30^{\circ}$  [3].

### 2.2. Experiment geometry

In the original geometry, the detector and the source were fixed and the tested object rotates along an axis perpendicular to the detector. This scanning geometry is known as fan beam scheme (see figure 1). A sinogram is the result image (see figure 2). Reconstruction reveals the internal structure of one slice with one pixel in height. Thus, to obtain a volumetric representation of an object one should transfer the detector along vertical direction step by step.

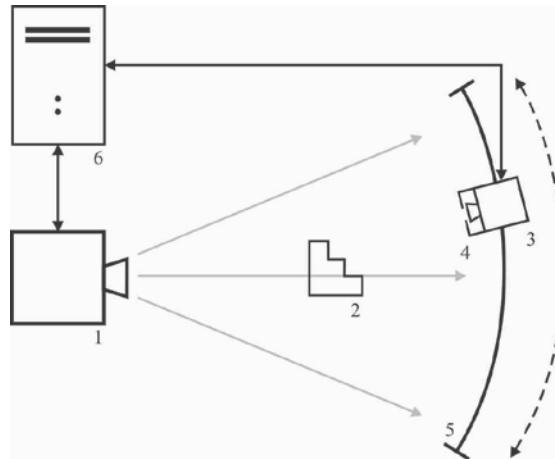


**Figure 1.** The original scheme of the setup: 1 – the X-ray tube; 2 – an object; 3 – the multi-channel gas-discharge X-ray detector; 4 – a computer.



**Figure 2.** Sinogram of the test module obtained from the multi-channel gas-discharge X-ray detector PRIZ 1536.

In the new geometry scheme, only X-ray source was fixed. Rotary stage with the test object is adjusted between X-ray source and detector to obtain necessary magnification and voxel size. The detector is set up vertically and moves across X-ray beam by means of its own manipulator. The new geometry scheme is shown on the figure 3. While the detector moves it collects full X-ray projection of the test object. Then object rotates and the next projection is acquired. As a result, necessary X-ray data to volumetric reconstruction are collected.



**Figure 3.** The new scheme of the setup: 1 – the X-ray tube; 2 – an object; 3 – scanning path of the detector; 4 – the multi-channel gas-discharge X-ray detector; 5 – the way of detector manipulator; 6 – a computer.

### 2.3. Test object

As the test object, we used AAPM CT Performance Phantom 610 for performance evaluation and quality assurance of clinical CT-scanners [4]. The phantom has overall dimensions of 21.6 cm in diameter and 39.4 cm in height. The exterior of the phantom is shown on figure 4.



**Figure 4.** The exterior of AAPM CT Performance Phantom, model 610.

The phantom includes several inserts to measure the key parameters of CT scanners such as spatial and contrast resolution, CT numbers linearity, slice thickness and some others. Thus, the phantom is a proper test object to evaluate the performance of the developed setup due to its size and different included inserts.

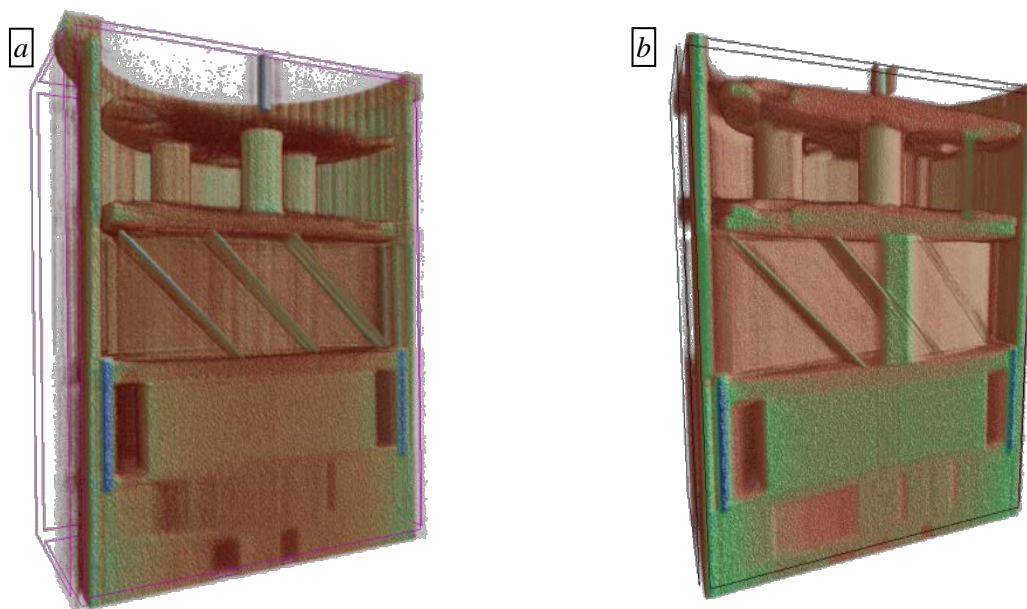
#### 2.4. Image processing

The updated geometry scheme is close to cone-beam geometry widely used in tomographic scanners. For reconstruction of volumetric data, we applied the Nrecon software (made by Bruker microCT, Belgium). This software employs FDK algorithm for cone-beam geometry [5] and allows different enhancement techniques for image processing such as beam hardening correction, ring artifact reduction and smoothing [6]. For volumetric visualization we applied the CTvox software made by Bruker microCT as well. The software allows to operate with the full slice stack, to apply virtual lighting, to change point of view and other actions. To analyze slices and to make measurements on images, we used the “ISee!” software developed in Federal Institute for Materials Research and Testing (Berlin, Germany) [6].

### 3. Results and discussions

We have carried out two experiments to evaluate possibilities of volumetric tomography by means of the multi-channel gas-discharge X-ray detector PRIZ 1536. The scanning geometry in both experiments was the same. The distance between the source and the test object was 2440 mm and the distance between the source and the detector was 3490 mm, thus the geometry magnification was 1.43. The pitch of detecting elements is 0.261 mm, consequently, the voxel size is 0.183 mm.

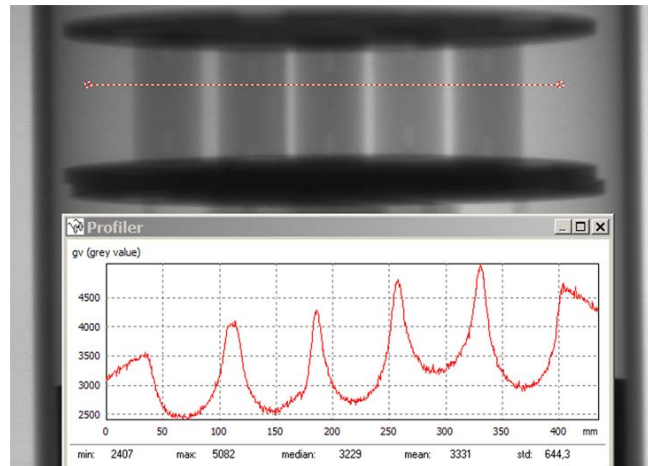
The voltage was 140 kV, the current was 5 mA and filters were not applied in both experiments. The first test scan was made with 5 degree angle step and consists of 40 projections. The second scan was performed with 1 degree angle step to obtain 200 projections. The result of volumetric reconstruction after these experiments is shown on the figure 5.



**Figure 5.** Volumetric representation of the CT phantom after reconstruction:  
a – from 40 projections; b – from 200 projections.

As seen on figure 5a, the reconstructed test object suffers from artificial ripples which are caused by undersampling due to large angle step. Reconstruction from 200 projections is almost free from such artifacts. However, in both cases, the reconstructed phantom looks realistic.

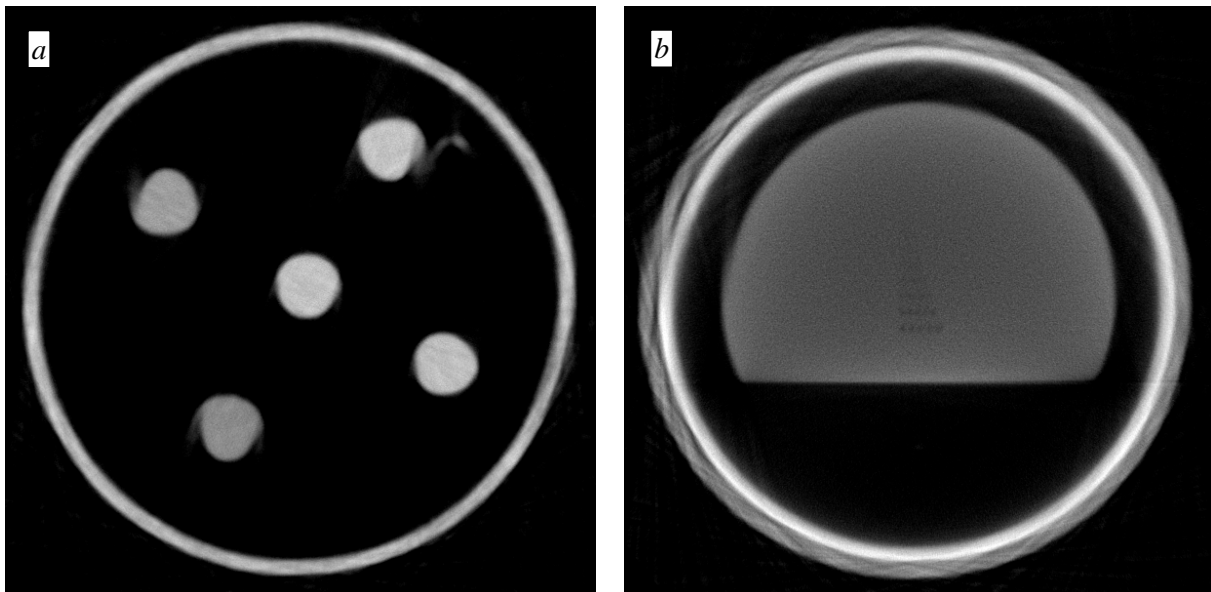
To evaluate contrast resolution we used the “ISee!” software. We chose one projection from the obtained data set where all cylinders in CT linearity insert are seen separately. Then, by drawing profiler line on the specific area we have got values of attenuated radiation. Figure 6 shows that all cylinders have different attenuation.



**Figure 6.** Contrast resolution of the projection shown by profiler line on the CT linearity insert of the phantom.

After the reconstruction procedure we analyzed contrast and spatial resolution of tomographic slices. As shown on the figure 7a, calibration cylinders have different gray values and that in agreement with their attenuation seen on the projection on figure 6.

On the figure 7b four rows of holes are seen. In addition, calibration wire is seen on the center of the image, closer to the bottom.



**Figure 7.** The slice of the CT: a – the linearity insert; b – the spatial resolution insert.

The analysis has shown that contrast resolution is a linear function, which means the tested detector demonstrate a proper sensitivity to X-ray attenuation. Spatial resolution is estimated as 0.28 mm or 1.8 lp/mm. The resulted resolution is lower than achievable value, which is equal to the voxel size or 0.182 mm. The main reason is movement of the detector across to the beam was not enough smooth and regular. Thus, different projections were not adjusted to the center of rotation. We believe that improvement of mechanical part would make possible to obtain better spatial resolution up to the value of the voxel size.

#### 4. Summary

In the modernized tomographic setup based on the multi-channel gas-discharge detector PRIZ-1536 a pulsed radiation source was replaced by the continuous X-ray tube Comet MXR-451HP/11. In addition, fan-beam geometry of scanning was changed into cone-beam one. These improvement made possible volumetric reconstruction and the proper contrast resolution was shown. So far, achieved spatial resolution is estimated as 0.280 mm or 1.8 lp/mm. Improving of resolution requires some minor changes in mechanical part of the setup. The field of view for the developed setup as big as 400×400 mm approximately and limited by the length of the detector and the scanning path of the mechanical system. Thus, the modernized setup is suitable for volumetric reconstruction of large object with high contrast resolution and submillimetric spatial resolution.

#### Acknowledgements

This work was financially supported by The Ministry of Education and Science of the Russian Federation in part of the science program (N 5.1485.2015).

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