The X-ray Beam Passage through the Collimator Made of Different Materials: Numerical Simulation

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Abstract. The X-ray beam application grows in the research investigations, in the medical diagnosis and treatment, in the industry. In this paper the theoretical model of the actual pulsed X-ray generator RAP-160-5 beam developed in the program "Computer Laboratory (PCLab)" is shown. The simulation data of the X-ray beam profile and shape collimated by different materials (gypsum, corund-zirconia ceramic, lead) are illustrated.

1. Introduction

The X-ray sources have a wide range of application, for example for the radiographic analysis in the nondestructive and medical examinations [1–6]. In this regard, the possibility to manage of the X-ray beam parameters in accordance with specific purposes is an actual task. As it is known that the numerical simulation allows estimating the X-ray beam parameters, making it easier and faster to obtain these characteristics than the actual measurements. Nowadays, the theoretical model development of the X-ray beam is a contemporary task.

In this research the theoretical analysis of the pulsed X-ray generator RAP-160-5 beam was carried out. The first objective of this investigation was to create the actual X-ray beam model correspond to the experimental result obtained previously in the paper [7]. The models of the X-ray beam shape modulation were developed in the program "Computer Laboratory (PCLab)". The next objective of this research was to analyze the X-ray beam collimation by different materials (gypsum, corund-zirconia ceramic, lead).

2. Materials and methods

2.1. Emitting source

In this research the following parameters of the pulsed X-ray generator RAP-160-5 were used as the emitting source: the anode material is copper; the focal spot size is 1.2 ×1.2 mm; the angular divergence of a beam is 40º; the anode voltage varies from 40 to 160 kV; the anode current varies from 0.4 to 5 mA [8].

2.2. Simulation program

The program "Computer laboratory (PCLab)" version 9.5 was used for the generator RAP-160-5 X-ray beam model creation. Numerical simulation is carried out by applying the Monte Carlo method.

The software package allows calculating the propagation process of photons, electrons, protons and positrons in substance with specified characteristics [9].

2.3. Experiment geometry

In this investigation the simulation results of the copper anode X-ray continuous spectrum was used. The normal plane disc (diameter – 1.2 mm) monoenergetic X-ray source with energy of 70 kV, corresponding to the actual pulsed X-ray generator RAP-160-5 beam, was used in the numerical simulation. The source was located in front of the plexiglas output window (thickness – 2 mm; diameter – 40 mm).

In the first part of this research the geometry of experiment is correspond to the experimental setup in the paper [7]. At the distance from the output window equal to 35 mm the aluminum filter was installed (thickness – 1.1 mm) to reduce the contribution of soft X-rays of the spectrum.

In the second part of this research the collimated X-ray beam shape was analyzed. In the simulation with a collimated X-ray beam the output window was overlapped by the plates from different materials (collimator channel length – 5 mm and 30 mm) with a cylindrical hole (taper diameter – 30 mm). The collimator materials are gypsum, corund-zirconia ceramic and lead. The beam shape analysis was carried out in the air.

The figure 1 (a, b) illustrates the calculation geometry with noncollimated and collimated X-ray beams, correspondingly.

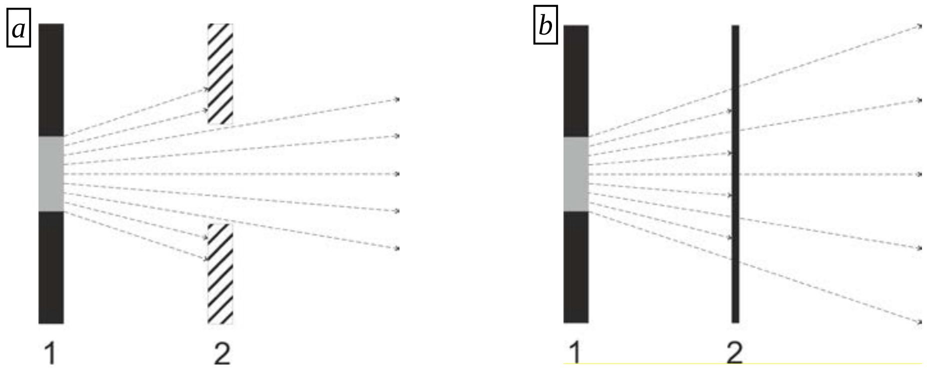


Figure 1. The simulation geometry:
a – noncollimated X-ray beam (1 – output window; 2 – an aluminum filter);
b – collimated X-ray beam (1 – output window; 2 – collimator).

3. Results and discussions

In the first part of this investigation the experimental and simulation results of the X-ray beam profile and shape were compared [7]. The figure 2 illustrates the measurement and simulation X-ray beam profile at the 30 cm distance from the X-ray tube focus.

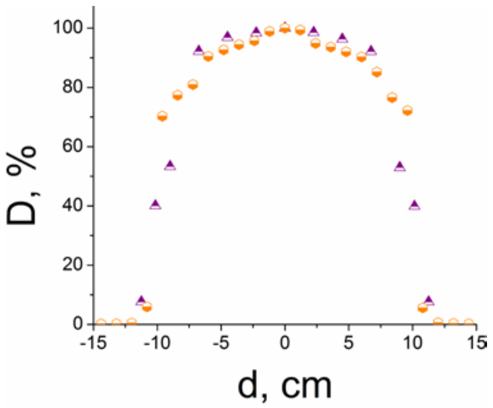


Figure 2. The X-ray beam profile at the 30 cm distance from the X-ray tube focus (the energy was 70 kV): ▲ – experimental results; ⬙ – simulation results.

The figure 2 shows that the model of the pulsed X-ray generator RAP-160-5 beam and the experimental results are in a good agreement. These points to the fact that this model can be used for the real X-ray beams analyze. The insignificant divergences between the obtained X-ray beam profiles in the figure 2 can be explained by the following factors: the size of the plane-parallel ionization chamber type 23342 effective area; an inaccuracy of the experiment geometry reproduction; the ideal numerical simulation area.

In the second part of this investigation the X-ray beam collimation by different materials are analyzed. In the figure 3 (a, b, c) the simulation data of the pulsed X-ray generator RAP-160-5 beam shape with the gypsum, corund-zirconia ceramic and lead collimator (channel length – 5 mm, taper diameter – 30 mm) at 30 cm distance from the X-ray tube focus are shown, correspondingly. The dose results were normalized to the maximum simulation dose in the layer.

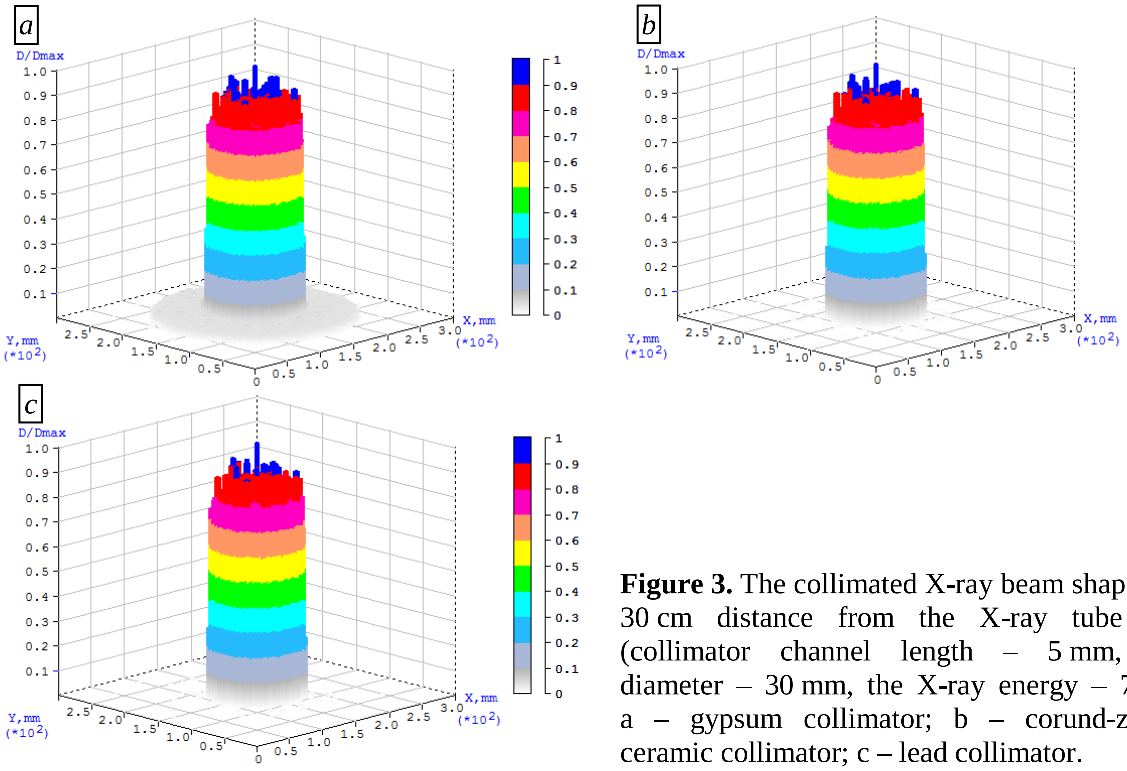
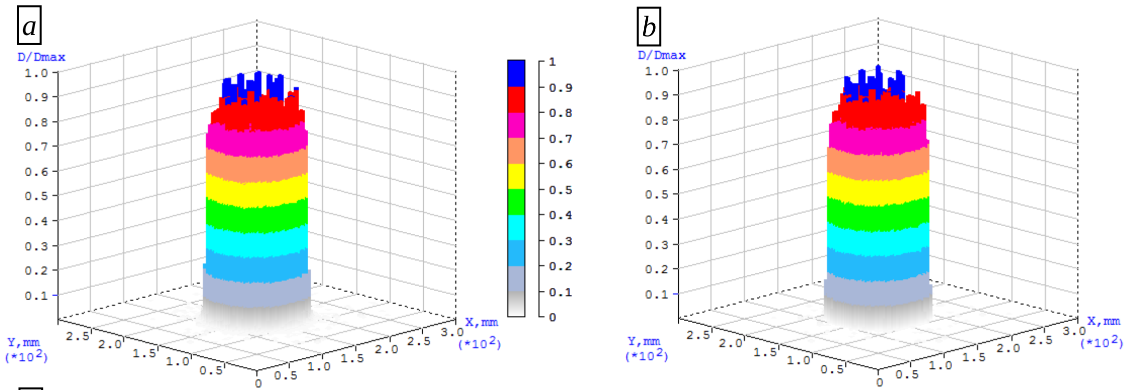


Figure 3. The collimated X-ray beam shape at the 30 cm distance from the X-ray tube focus (collimator channel length – 5 mm, taper diameter – 30 mm, the X-ray energy – 70 kV): a – gypsum collimator; b – corund-zirconia ceramic collimator; c – lead collimator.

In the figure 4 (a, b, c) the simulation data of the pulsed X-ray generator RAP-160-5 beam shape with the gypsum, corund-zirconia ceramic and lead collimator (channel length – 30 mm, taper diameter – 30 mm) at 30 cm distance from the X-ray tube focus are shown, correspondingly. The dose results were normalized to the maximum simulation dose in the layer.

The simulation model (figures 3, 4) shows that the gypsum collimator can be used with the collimator channel length is equal to or greater than 30 mm, the corund-zirconia ceramic and lead collimators can be used with the collimator channel length is equal to or greater than 5 mm, this material thickness is enough to absorb the X-ray beam with the 70 kV energy. The obtained results illustrates that the dose in the layer has the regularly spaced distribution in the collimation area.



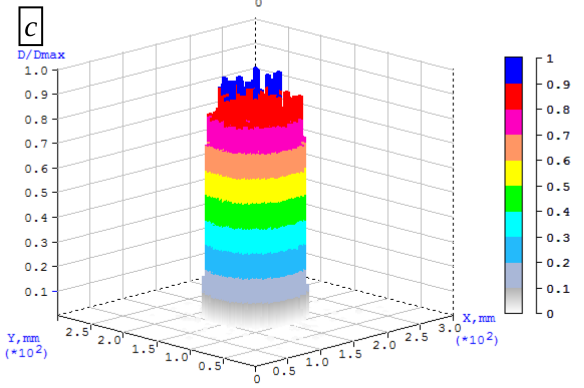


Figure 4. The collimated X-ray beam shape at the 30 cm distance from the X-ray tube focus (collimator channel length – 30 mm, taper diameter – 30 mm, the X-ray energy – 70 kV): a – gypsum collimator; b – corund-zirconia ceramic collimator; c – lead collimator.

4. Summary

In this paper the theoretical model of the actual pulsed X-ray generator RAP-160-5 beam was developed in the simulation program “Computer laboratory (PCLab)”. The calculation data show the suitability of this program for the real X-ray beams analyzing. The obtained results allow modulating the X-ray beam profile and shape for the specific practical task using the different type of the collimation devices. The next step of this research is an experimental approbation of the obtained simulation data of the collimated X-ray beam.

Acknowledgements

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