

Application of Traditional and Nanostructure Materials for Medical Electron Beams Collimation: Numerical Simulation

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Abstract. Nowadays, the commercial application of the electron accelerators grows in the industry, in the research investigations, in the medical diagnosis and treatment. In this regard, the electron beam profile modification in accordance with specific purposes is an actual task. In this paper the model of the TPU microtron extracted electron beam developed in the program “Computer Laboratory (PCLab)” is described. The internal beam divergence influence for the electron beam profile and depth dose distribution in the air is considered. The possibility of using the nanostructure materials for the electron beam formation was analyzed. The simulation data of the electron beam shape collimated by different materials (lead, corund-zirconia nanoceramic, gypsum) are shown. The collimator material influence for the electron beam profile and shape are analyzed.

1. Introduction

At the present time particle accelerators and X-ray sources have a wide range of application [1–4]. One of the most promising radiations is the electron beams with different energies, which are widely used in such clinical areas as medical diagnosis, external-beam radiotherapy and intraoperative radiotherapy [5]. The clinical electron beam application needs to have an exact representation of the beam profile and shape and be able to manage the parameters in accordance with specific purposes. As it is known the numerical simulation allows estimating the electron beam parameters, making it faster and easier to obtain beam characteristics than the practical measurements. In this regard, the electron beam model development is an topical issue.

As it is known the nanostructure materials can be used in cancer treatment. Nanotechnology research in this area ranges from the diagnostics and therapeutics with the use of nanoparticles to the production of the dendrimers for boron neutron capture therapy [6–7]. One of the perspectives is to use the nanostructured materials for the electron beam formation.

In this research the suitability of the industrial nanoceramics was analyzed for these purposes. Up to date, submicrocrystalline nanoceramics based on zirconia and alumina compositions are intensively studied because of their service properties [8–9]. In this research the corund-zirconia nanoceramic was analyzed as a collimation material.

Nowadays, there are a lot of foundations of the new collimation materials for the electron beam. One of the perspectives is to use the 3D-printer materials for the accelerator beam collimator production. The 3D printed structures are useful in the different medical and industrial areas, because of the possibility to change the material property for the task-specific [10–12]. In this paper the gypsum composite was chosen from a wide range of 3D printing materials, since it is widely distributed and is relatively cheap raw material.



Within the framework of this investigation the theoretical analysis of the Tomsk Polytechnic University (TPU) microtron extracted electron beam was carried out. The models of the accelerator electron beam shape modulation were developed in the program “Computer Laboratory (PCLab)”. The following factors, affecting of the electron beam profile are analyzed: the internal beam divergence, beam collimation by different materials (lead, corund-zirconia nanoceramic, gypsum).

2. Materials and methods

2.1. Collimation materials

We analyzed the corund-zirconia nanoceramic for the electron beam formation. The lead was used as the classical material for the electron beam collimator production. As the cheaper alternative the gypsum was selected.

2.2. Emitting source

The following parameters of the TPU microtron extracted electron beam were used as the emitting source: electron energy – 6.1 MeV; beam size at output $\approx 2.0 \text{ mm}^2$; beam divergence – 0.1 rad.

2.3. Simulation program

The program “Computer laboratory (PCLab)” version 9.5 was used for the TPU microtron extracted beam model creation. Simulation is carried out by applying the Monte Carlo method. The software package allows calculating the propagation process of electrons, positrons, protons and photons in matter with specified characteristics [13].

2.4. Experiment geometry.

The normal plane disc (diameter – 2.0 mm) monoenergetic electron source with energy of 6.1 MeV, corresponding to the actual TPU microtron beam, was used in the simulation. The source was located in front of the beryllium output window (thickness – 50 μm ; diameter – 40 mm). The beam shape analysis was carried out in the air.

In the simulation with a collimated electron beam in the first instance the output window was overlapped by the plates from different materials (collimator channel length – 5 mm and 10 mm) with a taper hole (taper diameter increased from 0.5 mm to 1.5 mm). The collimator materials are lead, corund-zirconia nanoceramic and gypsum.

The figure 1 (a, b) illustrates the calculated path particles in the geometries with noncollimated and collimated electron beams, in view of photon production, correspondingly.

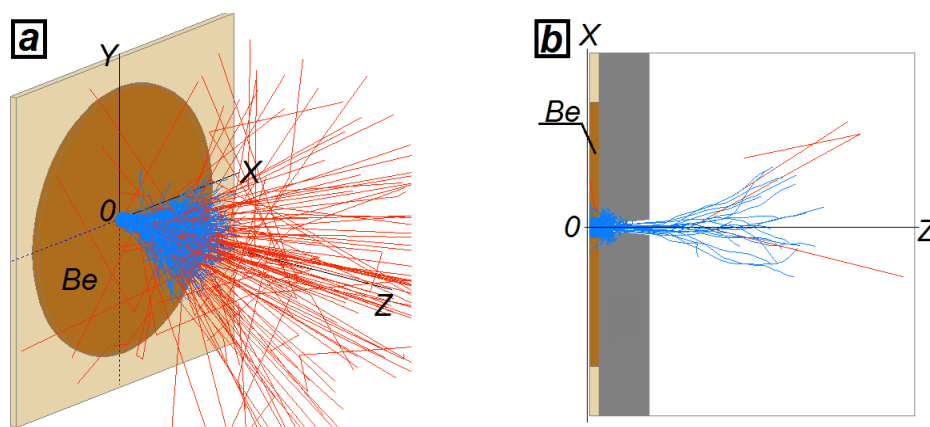


Figure 1. The calculated path particles: a – noncollimated electron beam; b – collimated electron beam; blue lines – electron path; red lines – photon path.

3. Results and discussions

In the figure 2 the simulation data of the TPU microtron extracted electron beam profile and shape at the 2 cm distance from the output window ignoring the internal beam divergence and taking into account the internal beam divergence are shown. The dose results were averaged and normalized to the maximum simulation dose.

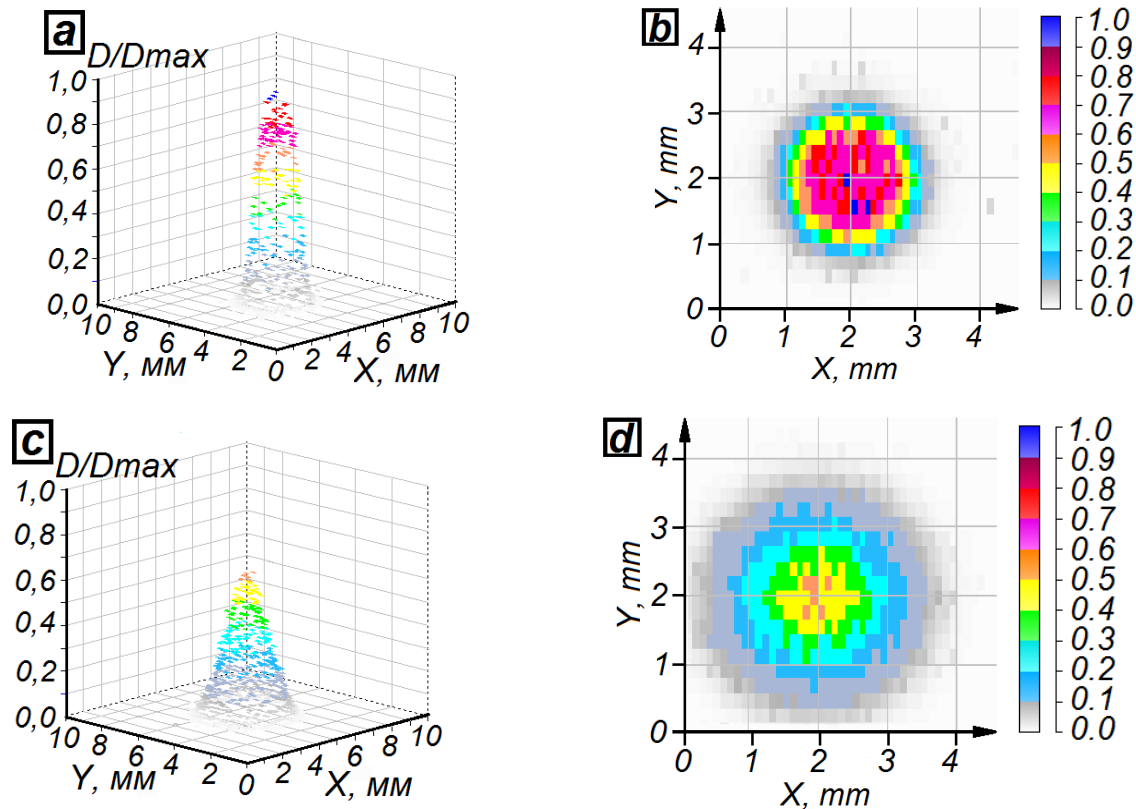


Figure 2. The TPU microtron extracted electron beam profile and shape at the 2 cm distance from the output window: a, b – ignoring the internal beam divergence; c, d –taking into account the internal beam divergence.

The figure 2 illustrates that increasing the internal beam divergence of the electron in the accelerator, the radiation dissipates faster than monodirectional beam. As a result it can be observed the dramatic drop of the dose and the beam broadening.

The figure 3 presents the simulation data of the TPU microtron extracted electron beam depth dose distribution in the air taking into account and ignoring the internal beam divergence.

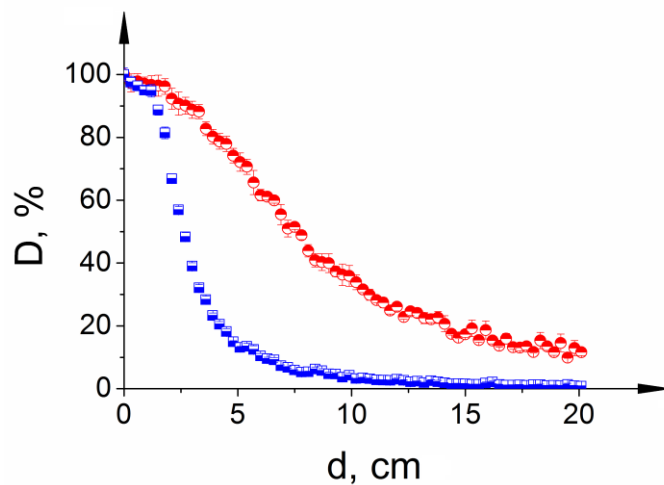


Figure 3. The TPU microtron extracted electron beam depth dose distribution in the air: ● – ignoring the internal beam divergence; ■ – taking into account the internal beam divergence.

The figures 2, 3 show that accounting the internal beam divergence of the electron in the accelerator, which is typical for real machines, significantly affects for the calculations results.

In the figure 4 (a, b) the simulation data of the TPU microtron collimated extracted electron beam shape with the lead collimator channel length equal to 5 mm and 10 mm at the collimator output with taking into account the internal beam divergence are shown, correspondingly.

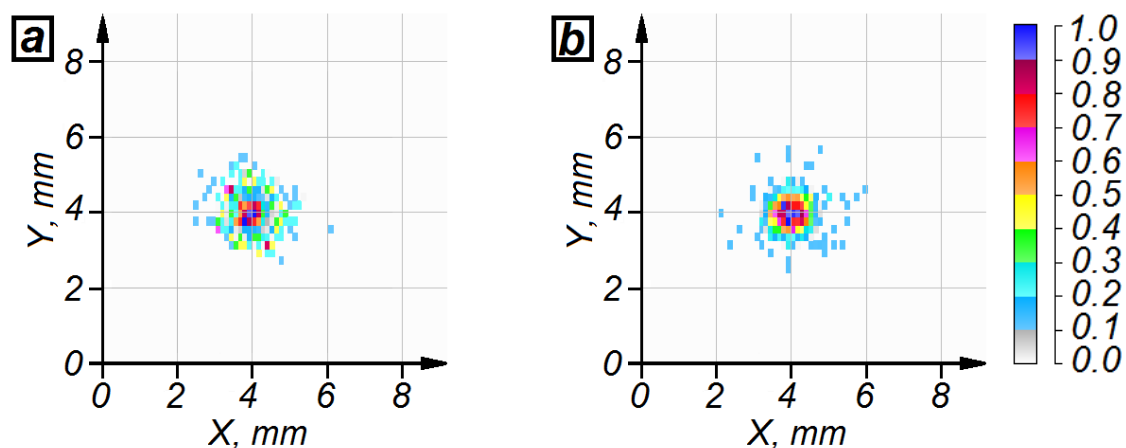


Figure 4. The TPU microtron collimated extracted electron beam shape at the lead collimator output: a – collimator channel length equal to 5 mm; b – collimator channel length equal to 10 mm.

The figure 4 illustrates that within the collimation window the dose distribution doesn't change significantly, but with the increasing lead collimation channel length the scattered radiation contribution is greatly reduced because of the large absorption.

In the figure 5 (a, b) the simulation data of the TPU microtron collimated extracted electron beam shape with the corund-zirconia nanoceramic collimator channel length equal to 5 mm and 10 mm at the collimator output taking into account the internal beam divergence are shown, correspondingly.

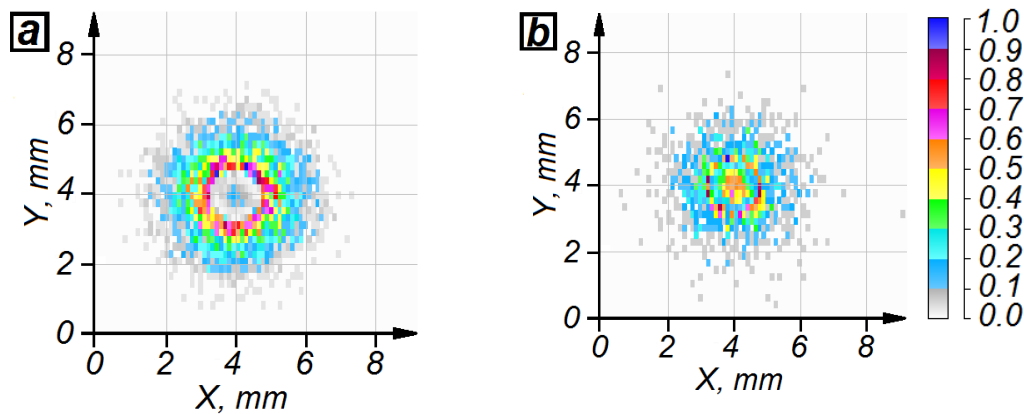


Figure 5. The TPU microtron collimated extracted electron beam shape at the corund-zirconia nanoceramic collimator output: a – collimator channel length equal to 5 mm; b – collimator channel length equal to 10 mm.

The simulation model (figure 5) shows that the dose maximum is observed in the region of the scattered and direct radiation contribution. The dose reduction is observed in a region of the only direct radiation. The dose decreases with the increasing of the deflection angle in the field of the scattered radiation. With the corund-zirconia nanoceramic collimator channel length equal to 5 mm the dose gradient is less than 10 cm because of the range increasing the scattered radiation in the collimator material.

In the figure 6 (a, b) the simulation data of the TPU microtron collimated extracted electron beam shape with the gypsum collimator channel length equal to 5 mm and 10 mm at the collimator output taking into account the internal beam divergence are shown, correspondingly.

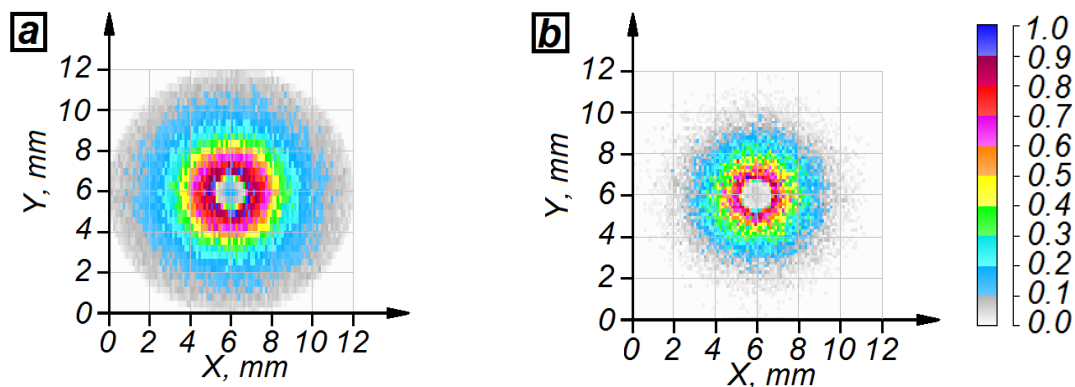


Figure 6. The TPU microtron collimated extracted electron beam shape at the gypsum collimator output: a – collimator channel length equal to 5 mm; b – collimator channel length equal to 10 mm.

The figure 6 illustrates that the shape of the electron beam at the gypsum collimator output determined by the same parameters as for corund-zirconia nanoceramic collimator (figure 5). However, the dimensions of the scattered radiation area are comparatively more due to the interaction nature of the collimator material with the electron and photon radiation.

4. Conclusion

In this paper the theoretical model of the TPU microtron extracted electron beam was calculated in the simulation program “Computer laboratory (PCLab)”. The obtained results show the suitability of this program for the real electron beams analyzing and for the beam shape modulation using the different type of the collimation devices, for example this program can be used in betatron for the radiation treatment.

The obtained results show that the corund-zirconia nanoceramic exhibit more efficiency than the gypsum and can be used for the electron beam formation instead of the traditional material after the collimator-geometry optimization.

The calculation data allow estimating the electron beam size and dose distribution at the selected distance from the output window. The depth dose distribution allows estimating the radiation burden values in the electron beam propagation direction. The obtained results allow simulating the collimators for the electron beam parameters optimization necessary for the specific practical task. The next step of this research is an experimental evaluation of the obtained simulation data.

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