Numerical Simulation of the Microtron Electron Beam Absorption by the Modified ABS-Plastic

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Abstract. Each specific task of the electron beam application imposes requirements for the beam profile and shape. One of the methods allows achieving high accuracy and low cost of the filters production is the 3D print method. The required properties of the electron beam interaction with the material can be achieved by using the modified plastic filaments. In this paper, the results of the model creation of the electron beams interaction with the ABS-plastic doped with different concentrations are presented. The depth dose distributions of the electron beam in the modified ABS-plastic are sown. The electron beam profiles and the electron beam distribution in the modified ABS-plastic are illustrated.

1. Introduction

Nowadays, the electron beams in common with photons and neutron have a wide range of application in the medical science and industry [1–8]. Each specific task of the electrons application imposes requirements for the beam profile and shape. In this case it is necessary to create the new method of the electron beam modulation. Certainly, the advanced directions of the development are such as that allow increasing the accuracy and rapidity of the filters production and reducing their cost.

Using 3D print methods allows achieving low cost, high accuracy and speed of the electron beams filter production [9–10]. One of the most common materials for 3D-printing is the ABS-plastic [11]. Adding a mixture of the heavier elements in a plastic filament allows to influencing on the nature of the electron beam interaction with the material. The first stage of the research in this direction is the theoretical estimation of the electron beams interaction with the various materials.

In this investigation the theoretical analysis of the electron beams interaction with the ABS-plastic doped with different concentrations of lead by means of numerical simulation TPU microtron extracted electron beam with energy equal to 6.1 MeV was carried out.

2. Materials and methods

2.1. Test materials

The test material density for the numerical simulation was selected according to the real anatomical structure density, for example, muscular tissue density ≈ 1.06 g/cm^3; skin density ≈ 1.1 g/cm^3; bone tissue 2.4 g/cm^3 [12].

In this research, the ABS-plastic doped with different concentrations of lead was used as test materials. The test materials density was calculated by:

$$\rho = \frac{\rho_{\text{ABS}} \cdot \rho_{\text{Pb}}}{k \cdot \rho_{\text{ABS}} + (100 - k) \cdot \rho_{\text{Pb}}}, \quad (1)$$

were ρ_{ABS} – the ABS-plastic density; ρ_{Pb} – the lead density; k – ratio of the lead mass concentration in the test material.

The dependence of the test material density from the lead mass concentration is presented on the figure 1.

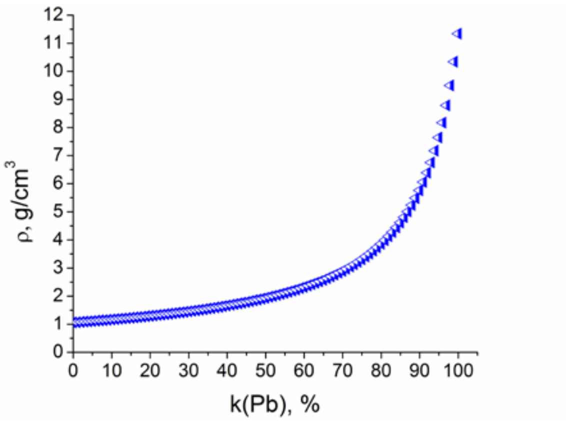

Figure 1. The dependence between the test material density and the lead mass concentration.

2.2. Emitting source

The TPU microtron extracted electron beam, with the following characteristics was used as the emitting source: beam size at output ≈ 2.0 mm^2; beam divergence – 0.1 rad; electron energy – 6.1 MeV.

2.3. Simulation program

In this investigation the program "Computer laboratory (PCLab)" version 9.6 was used for the model creation of the TPU microtron extracted electron beam. In this software package the Monte Carlo method applies for the numerical simulation of the propagation process of electrons, protons, photons and positrons in matter with specified characteristics [13].

2.4. Experiment geometry

In the numerical simulation the irradiation source has the following parameters: particle type – electron; source type – normal plane disc (diameter – 2.0 mm); electron energy – 6.1 MeV. These parameters correspond to the actual TPU microtron beam. The source was placed in front of the beryllium output window (diameter – 40 mm; thickness – 50 μm). The beam shape analysis was carried out in the ABS-plastic doped with different concentrations of lead.

3. Results and discussions

In the first phase of the experiment the depth dose distribution of the electron beam in the ABS-plastic doped with different concentrations of lead was obtained (figure 2). In the figure 3 an example of the electron beam profile obtained by simulation are shown at the 5 cm distances from microtron output window.

The figures 2, 3 show that small change of the heavy elements concentration in the plastic filament significantly affects on the character electron beam interaction with the material.

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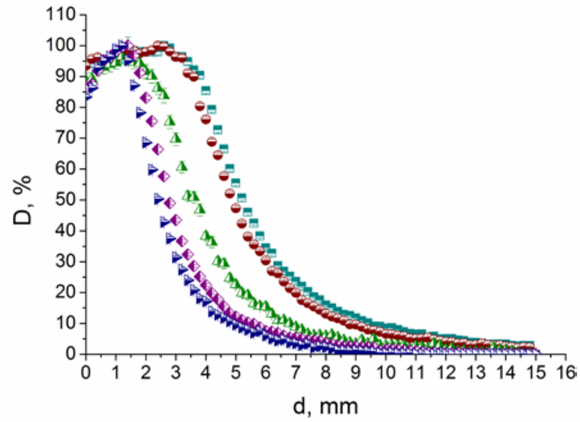

Figure 2. The depth dose distribution of the electron beam in the test materials.

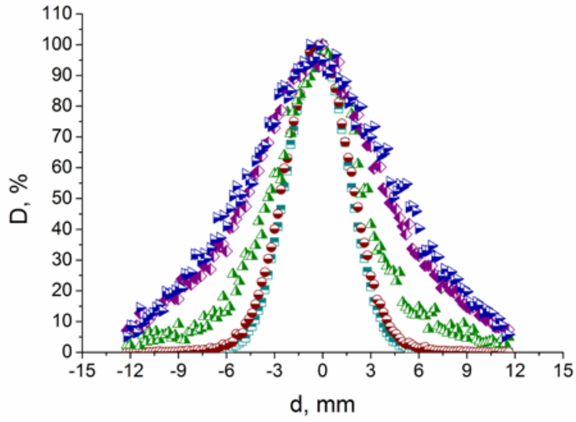

Figure 3. The electron beam profiles in the test materials at the distance from microtron output window equal to 5 cm.

The modified ABS-plastic density: ▬ – 1.06 g/cm^3; ◒ – 1.1 g/cm^3; ▲ – 1.5 g/cm^3; ◆ – 2.0 g/cm^3; ▶ – 2.5 g/cm^3.

In the figures 4, 5 examples of the electron beam distribution in the horizontal plane obtained by simulation in the modified ABS-plastic are presented. The dose results were averaged and normalized to the maximum simulation dose in the layer.

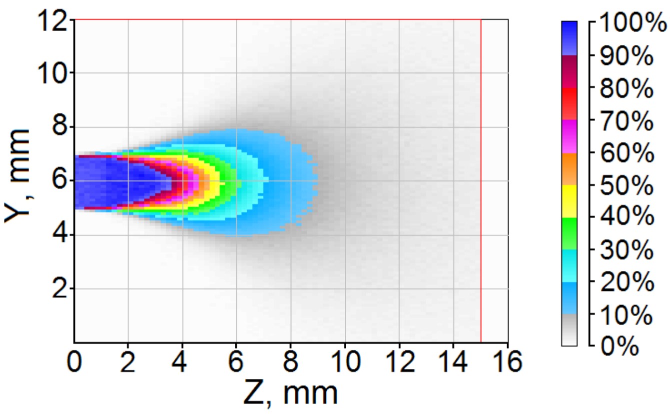

Figure 4. The electron beam distribution in the horizontal plane (the modified ABS-plastic density – 1.1 g/cm^3).

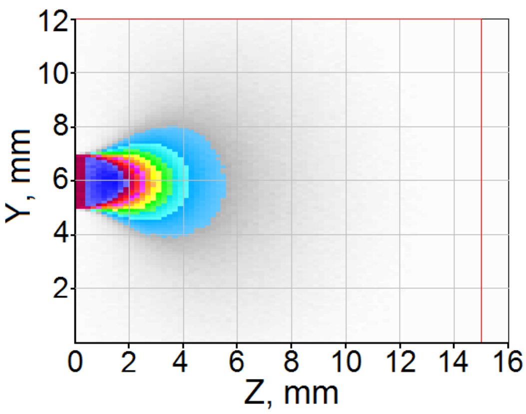

Figure 5. The electron beam distribution in the horizontal plane (the modified ABS-plastic density – 2.5 g/cm^3).

In the figures 6, 7 examples of the electron beam shape in the vertical plane at the distance from microtron output window equal to 5 cm in the modified ABS-plastic are shown. The dose results were averaged and normalized to the maximum simulation dose in the layer.

Presented examples of the calculated cross sections of the radiation dose distributions (figures 4–7) show that the radiation absorption is faster and the layers with the highest dose are closer to the surface on the filter with higher density. Additionally, the higher density of the material leads to the higher electron beam scattering, that is in agreement with the theory.

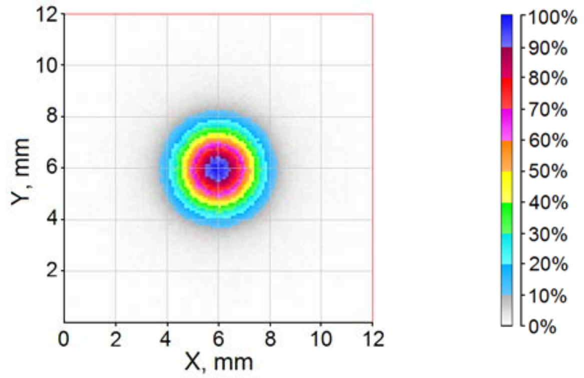

Figure 6. The electron beam shape in the vertical plane at the distance from microtron output window equal to 5 cm (the modified ABS-plastic density – 1.1 g/cm^3).

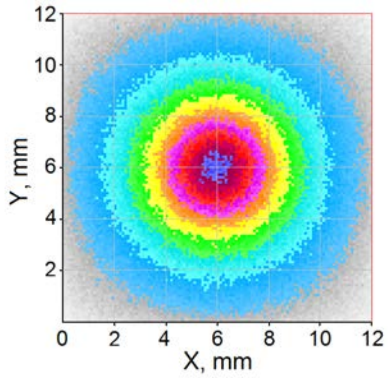

Figure 7. The electron beam shape in the vertical plane at the distance from microtron output window equal to 5 cm (the modified ABS-plastic density – 2.5 g/cm^3).

4. Summary

In this investigation the theoretical analysis of the electron beams interaction with the modified ABS-plastic by means of numerical simulation TPU microtron extracted electron beam was carried out. The results show the possibilityof the “Computer laboratory (PCLab)” using for the analysis of the real electron beam interaction with the modified materials.

It is shown that small change of the heavy elements concentration in the plastic filament significantly affects on the character electron beam interaction with the material. The next phase of this investigation it is necessary to produce the ABS-plastic doped with different concentrations of lead, then to obtained the real density and the Hounsfield’s units of the modified ABS-plastic and then to estimate the radiation resistance of the materials. Than if it will be needed to correct the numerical model.

Acknowledgements

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