The Dosimetric Parameters Investigation of the Pulsed X-ray and Gamma Radiation Sources

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Abstract. The most common type of radiation used for diagnostic purposes are X-rays. However, X-rays methods have limitations related to the radiation dose for the biological objects. It is known that the use of the pulsed emitting source synchronized with the detection equipment for internal density visualization of objects significant reduces the radiation dose to the object. In the article the analysis of the suitability of the different dosimetric equipment for the radiation dose estimation of the pulsed emitting sources is carried out. The approbation results on the pulsed X-ray generator RAP-160-5 of the dosimetry systems workability with the pulse radiation and its operation range are presented. The results of the dose field investigation of the portable betatron OB-4 are demonstrated. The depth dose distribution in the air, lead and water of the pulsed bremsstrahlung generated by betatron are shown.

1. Introduction

Recent years around the world characterized by rapid technological development for digital X-ray diagnostic devices, and as a consequence of the emergence of a variety of technical solutions based on these technologies. Today, the object's internal density visualization based on the X-ray methods is used in many fields of science, medicine and industry [1–4].

However, the development of recent decades do not allow to achieve a quantum leap in reducing the radiation dose to the object under investigation, the values of which are often very important, especially in medical diagnostic procedures. One of this problem possible solution is using the pulsed emitting source synchronized with the detection equipment.

In recent years the technological research and development for creation a radiographic equipment based on pulsed sources that meets modern requirements and reduces radiation doses for the investigated object is working hard [5–9]. In the basis of these sources can be linear accelerators, betatrons, microtrons and pulsed X-ray tubes.

The results of the development of the visualization devices based on the pulsed X-ray source and the radiation dose estimation are described in the articles [9–10]. A further object of the investigation is the development of the tomographic system based on the pulsed bremsstrahlung generated by betatron.

For the investigations the gamma beam equability, the dose rate spatial distribution, the depth dose distribution in the different areas it is necessary to select the dosimetric equipment capable of working with the pulsed radiation of the corresponding intensity and radiation spectrum. The problem consists in that the pulsed source emits portions; consequently, the dose rate in the impulse is essentially bigger than the average values. In addition, the pulse-repetition rate is high enough and the profile of the beam intensity is fast-changing. Thus, specific requirement for response rate of the recording equipments are arisen in these conditions [10]. The applied dosimetric equipment should have quick response and be capable of working with the sufficiently high dose rates.

The main objective of the research was to analyse the suitability of the different dosimetric equipment for the radiation dose estimation of the pulsed emitting source and to choose the most appropriate ones. In the first phase the dosimetric equipments were investigated by means of pulsed X-ray tube. As a result the suitable dosemeters and its operation range of the energies and the intensities of radiation were selected. The next phase was to estimate the radiation dose of the pulsed bremsstrahlung generated by betatron OB-4. The depth dose distribution in the air, lead and water of the pulsed bremsstrahlung were obtained. The spatial profile of the dose rate of the pulsed bremsstrahlung generated by betatron was measured, the gamma beam equability was estimated. The suitability of using the compact pulse betatron OB-4 as a source of bremsstrahlung for visualization purposes was analysed.

2. Materials and methods

2.1. Emitting source

In the experiment the pulsed X-ray generator RAP-160-5 (portable radiological apparatus) and the portable betatron OB-4 were used as a source of emission. These devices are producing in the small innovation business in the Tomsk Polytechnic University.

The general quantities of the pulsed X-ray generator RAP-160-5 are: the anode voltage varies from 40 to 160 kV; the anode current varies from 0.4 to 5 mA; the focal spot size is 1.2 ×1.2 mm; the angular divergence of a beam is 40º; the frequency of radiation impulse varies from 60 to 700 Hz; the duration of one pulse is about 140 μs; pulse form is close to squared shape. The X-ray generator can be synchronized with the other devices [11].

The portable betatron OB-4 is used as a pulsed source of bremsstrahlung. The material of the target is tungsten (0.6 cm thick). The general quantities of the portable betatron OB-4 are: the maximum kinetic energy of the accelerated particles is 4.0 MeV; the frequency of radiation impulse is 400 Hz; the duration of one pulse is about 15 μs [12].

2.2. Dosimetric equipment

The main problem associated with the dosimetry of the pulsed radiation is the response rate of the dosimeters. This problem can be solved by using the storage type of the detectors. The solid thermoluminescent dosimeters DTL-02 were used as dosimetric equipment for initial estimation of the radiation doses. The thermoluminescent material of the detectors is LiF: Mg, Ti. The detectors annealing temperature is 400ºC. The dosimetric complex based on the thermoluminescent dosimeters DTL-02 is designed for the personal dosimetry [13]. The dosimeter-radiometer DKS-96 equipped with a detection unit BDMG-96 was used for radiation dose estimation of the pulsed X-ray [14].

The universal dosimeter for radiation therapy and diagnostic radiology UNIDOS E equipped with a PTW soft X-ray plane-parallel ionization chamber type 23342 and with a PTW Farmer chamber type 30013 was used in the experiments [15]. The PTW soft X-ray plane-parallel ionization chamber type 23342 (the sensitive volume is 0.02 cm^3) is used for absolute dosimetry of soft X-ray beams [16]. The PTW Farmer cylindrical ionization chamber type 30013 (the sensitive volume is 0.6 cm^3) is used for absolute photon and electron dosimetry. This chamber is waterproof and can be used in water or in solid-state phantoms [17].

2.3. Experimental setup

In the experiment using the pulsed X-ray generator RAP-160-5 between the X-ray generator and the dosimetric equipment an aluminum filter was installed (half-value layer) to reduce the contribution of soft X-rays of the spectrum, which did not correspond to the dosimeters operating modes.

In the experiment using the portable betatron OB-4 the irradiation source was placed in lead dome with the output window. The detector was positioned on the radiation axis opposite the output window.

For obtain the depth dose distribution in the lead of the bremsstrahlung generated by the accelerator the lead plates with the different thickness (0.3, 0.6, 0.8, 5.0 cm) was used.

For obtain the depth dose distribution in the water of the bremsstrahlung generated by the accelerator the water phantom 41023 for horizontal beams was used. The external phantom dimensions are approximately 30 cm × 30 cm × 30 cm. The entrance window in one of the walls has the thickness of 3 mm (the walls material is PMMA) and the size of 150 mm × 150 mm [18].

2.4. Radiation doses measurement technique of the pulsed X-ray source

One of the aims of the development is to find out the radiation doses estimation methods of the pulsed X-ray sources.

In the experiment the distance between the X-ray source focus and the detector varied from 40 cm to 60 cm. The radiation was produced by the following parameters of the X-ray tube: the anode voltage was 70 kV; the anode current varied from 0.6 to 3.5 mA.

In the experiment the thermoluminescent dosimeters DTL-02, the dosimeter-radiometer DKS-96 equipped with a detection unit BDMG-96, the dosimeter UNIDOS E equipped with an ionization chamber type 23342 were used for the dose measurements of the pulsed X-ray generator RAP-160-5.

In the next part of the experiment the universal dosimeter UNIDOS E equipped with the plane-parallel ionization chamber type 23342 was used for the measurements of the dose rates spatial distribution of the pulsed X-ray source.

2.5. Radiation dose measurement technique of the pulsed bremsstrahlung of the betatron

Another aim of the development is to use the compact pulse betatron OB-4 as a source of bremsstrahlung for visualization purposes. Therefore, it is necessary to develop the radiation dose estimation methods of the pulsed bremsstrahlung generated by the accelerator. The measurements were carried out in the three different arias: in the air, in the lead and in the water.

The irradiation source was placed in lead dome with the output window. The detector was positioned on the radiation axis opposite the output window. The thermoluminescent dosimeter DTL-02 was used for the dose measurements in the air of the pulsed bremsstrahlung generated by betatron.

In the second part of the experiment the dose and the dose rate measurements in the three different arias: in the air, in the lead and in the water were carried out by the universal dosimeter UNIDOS E equipped with the cylindrical ionization chamber type 30013.

In the experiment in the air the distance between the radiation source and the detectors was varied from 30 to 100 cm in increments of 10 cm. For obtain the depth dose distribution in the lead of the bremsstrahlung generated by the accelerator the lead plates were arranged on the radiation axis close by the output window, the detector was positioned opposite the lead plates. For obtain the depth dose distribution in the water of the bremsstrahlung generated by the accelerator the water phantom 41023 for horizontal beams was used.

2.6. The dose rate profile measurements technique of the pulsed bremsstrahlung of the betatron

For obtain better visualization results the dose rate spatial distribution of the pulsed bremsstrahlung of the betatron should be determined.

The universal dosimeter UNIDOS E equipped with the cylindrical ionization chamber type 30013 was used for the measurements of the dose rates spatial distribution of the pulsed bremsstrahlung generated by betatron. The measurements were carried out in the plane coinciding with the emitter axis. The angular divergence of a beam was scanned in the range of 70º in increments of 5º. The distance between the radiation source and the detectors was 100 cm. The scanning area is defined by the lead dome side dimension.

3. Results and discussions

The figure 1 shows the dependence between the dose rate of the pulsed X-ray beam and the anode current at the distance between the X-ray source focus and the detector equal to 50 cm (the anode voltage equal to 70 kV). The results show that the dose rate measurements obtained with the help of the solid thermoluminescent detectors DTL-02, the plane-parallel ionization chamber type 23342, the dosimeter-radiometer DKS-96 equipped with a detection unit BDMG-96 are in a good agreement and can be used for dosimetry measurements of the pulsed X-ray generator RAP-160-5.

In the figure 2 an example of the dose rate spatial distribution of the pulsed X-ray source at the 30 cm distance are shown. The dose rate measurement for the different X-ray tube parameters were averaged and normalized to 100%.

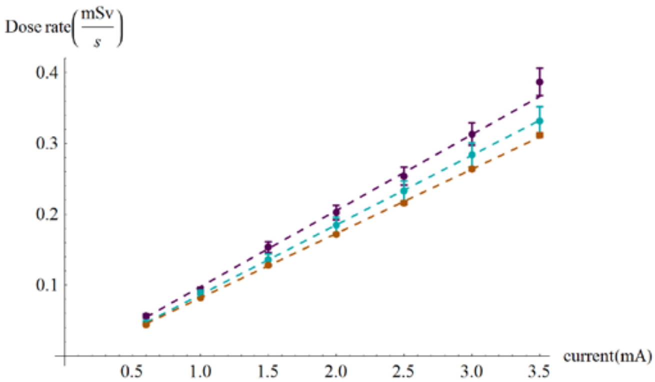

Figure 1. The dependence between the dose rate of the pulsed X-ray beam and the anode current:
● – the thermoluminescent dosimeters DTL-02;
● – the plane-parallel ionization chamber type 23342;
● – the dosimeter-radiometer DKS-96.

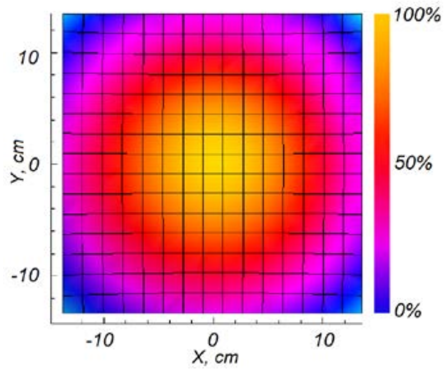

Figure 2. The dose rate spatial distribution of the pulsed X-ray source at the 30 cm distance. Array pitch is 2°.

The obtained data (figure 2) of the dose rate spatial distribution of the pulsed X-ray source show that at the distance between the X-ray source focus and the detector equal to to 30 cm – 20×20 cm for obtain better visualization results, because the dose rate spatial distribution is the most stable in this area. The obtained results show the dose rate dramatic decrease outside angular divergence of a beam (40°).

In the figure 3 the depth dose distribution in the air of the pulsed bremsstrahlung generated by betatron depend on the distance between the accelerator and the detector using the solid thermoluminescent dosimeters DTL-02 and the cylindrical ionization chamber type 30013 are presented.

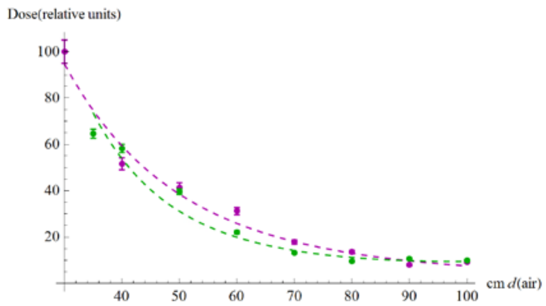

Figure 3. The depth dose distribution in the air of the pulsed bremsstrahlung generated by betatron OB-4:
● – DTL-02; ●– chamber 30013.

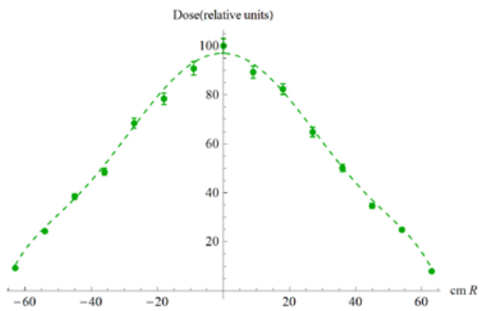

Figure 4. The dose rate profile of the pulsed bremsstrahlung generated by betatron OB-4:
● – chamber 30013.

It is shown (figure 3) that the results obtained with the help of the different types of the dosimeters are in a good agreement with each other.

In the figure 4 the dose rate profile of the pulsed bremsstrahlung generated by betatron are shown. The measurements were carried out in the plane coinciding with the emitter axis. The scanning area is defined by the lead dome side dimension. At the distance between the radiation source and the detector equal to 100 cm the angular variation equal to 5º is equivalent to 9 cm on a plane. The obtained data (figure 4) show the sufficient equability of the accelerator beam, which indicates the suitability of the emitting source for the visualization purpose.

The depth dose distribution in the water and in the lead of the pulsed bremsstrahlung generated by betatron depend on the distance between the accelerator and the detector using the cylindrical ionization chamber type 30013 are presented in the figure 5 and the figure 6 correspondingly. The obtained data (figure 5 and figure 6) show that the bremsstrahlung generated by betatron can be used for the visualization purposes of the objects in the nondestructive and medical examinations.

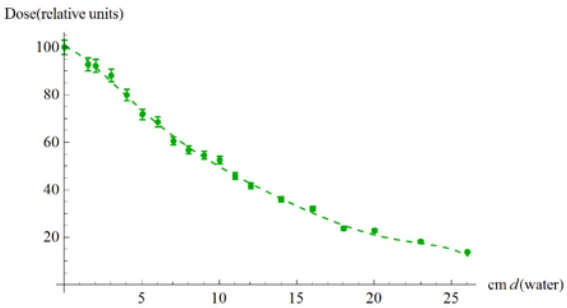

Figure 5. The depth dose distribution of the pulsed bremsstrahlung generated by betatron OB-4 in the water.

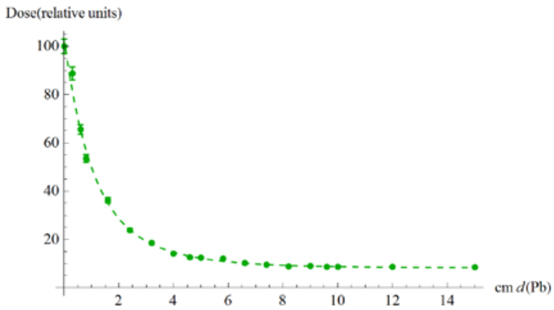

Figure 5. The depth dose distribution of the pulsed bremsstrahlung generated by betatron OB-4 in the lead.

4. Summary

The experimental results show the advisability of using the solid thermoluminescent dosimeters DTL-02, the dosimeter-radiometer DKS-96 equipped with a detection unit BDMG-96 and the universal dosimeter UNIDOS E equipped with a PTW soft X-ray plane-parallel ionization chamber type 23342 for the dosimetric parameters measurements of the pulsed X-ray generator RAP-160-5 under different radiation conditions. The obtained date show the advisability of using the solid thermoluminescent dosimeters DTL-02 and the universal dosimeter UNIDOS E equipped with a PTW Farmer chamber type 30013 for the dosimetric parameters measurements of the pulsed bremsstrahlung generated by electron accelerator with energy of 4 MeV. However, it should be noted that these dosimeters are effective at work with different energy and intensity of radiation.

After the dosimetric equipments selection the radiation dose of the pulsed bremsstrahlung generated by betatron OB-4 was estimated. The depth dose distributions in the lead and in the water of the pulsed bremsstrahlung were obtained. The profile of the depth dose distribution in the lead has an enough linear character for the adsorber thickness up to 3 cm, which indicates the suitability of the accelerator in the nondestructive testing goals. The profile of the depth dose distribution in the water has a linear character and demonstrates the suitability of radiation for visualization biological objects with thicknesses up to 25 cm, which is typical of the human body size.

The spatial profile of the dose rate of the pulsed bremsstrahlung generated by betatron and the depth dose distribution in the air was measured. The obtained data show the sufficient equability of the accelerator beam, which indicates the suitability of the emitting source for the visualization purpose. The obtained data show that the size of object under investigation should be about 50 cm in the plane perpendicular to the emitter axis for obtain better visualization results.

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