

Measurement Technique of Dose Rate Distribution of Ionization Sources with Unstable in Time Beam Parameters

S G Stuchebrov¹, I A Miloichikova² and I B Danilova³

¹ Senior Researcher, Tomsk Polytechnic University, Tomsk, Russia

² Engineer, Tomsk Polytechnic University, Tomsk, Russia

³ Bachelor student, Tomsk Polytechnic University, Tomsk, Russia

E-mail: stuchebrov@tpu.ru

Abstract. The article describes a new technique for the average values of radiation dose measurement for the unstable gamma-ray sources which are used in non-destructive testing. The method is based on usage of different types of compact accumulative dosimeters. Spatially distributed position sensitive dosimetry system based on compact sensitive elements was created. Size and spatial resolution of the system of the dosimetry system are chosen taking into account sources characteristics. The proposed method has been tested on the measurement of dose distribution of several sources of X-ray and gamma-radiation based on X-ray tubes, electronic accelerator betatrons and linear electron accelerators.

1. Introduction

The tendency for increasing the research results quality of the internal structure of products in the performance of nondestructive testing in industries is specified requirements on the stability characteristics of the probing beams and correspondingly, of their emitters [1–3]. Despite this, today is often used unstable X-ray and gamma-ray sources. The basic parameters of such sources are changing while working up to several tens of percent. The causes of the parameters changing are: the external pickups on the emitting source; the sensibility to the instability of the external power supply; the heating of the device; the imperfection of individual units of the emitting source. Such systems are used, for example, for the research purposes. This systems use the experimental equipment, debugging of which is often either not possible or does not make sense [4–6].

As a consequence, the use of such devices requires the measurement and monitoring of the characteristics of the dose fields. The variability of the parameters does not allow using of conventional methods based on the data acquisition from a single dosimeter moving within the radiation field because the unstable field must be measured simultaneously in the entire volume.

To solve this problem we studied the possibility of constructing a spatially distributed dosimetry system. For this purpose were used compact storage dosimeters placed in the space in a pre-calculated points dose radiation fields generators. The position detecting elements is caused by the shape of the radiation field of the test generator and the desired spatial resolution of the dosimetry system.

The investigations were carried out on various sources of X-ray and gamma-ray radiation. The spatial distributions of the pulsed X-ray generator RAP-160-5, of the X-ray generator RAP-60-25, of the portable betatron OB-4, of the pulsed electron accelerator "ASTRA" were obtained.



The obtained results showed the suitability of spatially distributed dosimetry systems for the radiation field analysis, including the pulsed sources which have a very sharp change of the beam profile and the high intensity within individual pulses.

2. Materials and methods

2.1. Emitting source

In the investigation the pulsed X-ray generator RAP-160-5, the X-ray generator RAP-60-25, the portable betatron OB-4 and frequency pulsed electron accelerator "ASTRA" were used as an emitting source.

The basic parameters of the pulsed X-ray generator RAP-160-5 are: the anode current is 0.4 – 5 mA; the anode voltage is 40 – 160 kV; the beam angular divergence is 40°; the focal spot size is 1.2 × 1.2 mm; the frequency of radiation impulse is 60 – 700 Hz; the duration of one pulse is about 140 μs [7].

The basic parameters of the X-ray generator RAP-60-25 are: the maximum anode current is 40 mA; the anode voltage is 20 – 60 kV; the beam angular divergence is 16° [8].

The portable betatron OB-4 was used as source of bremsstrahlung. The basic parameters of the portable betatron OB-4 are: the maximum energy is 4.0 MeV; the frequency of radiation impulse is 400 Hz; the duration of one pulse is about 15 μs [9]. The material of the target is tungsten (0.6 cm thick).

In addition to the betatron as a source of the bremsstrahlung was used the frequency pulsed electron accelerator "ASTRA". The general quantities of the accelerator "ASTRA" are: the maximum energy is 450 keV; the frequency of radiation impulse is 50 Hz; the duration of one pulse is about 60 ns [10].

2.2. Dosimetric equipment

The use of different types of the storage dosimeters such as thermoluminescent dosimeters DTL-02 and capacitor type dosimeters D-2R make it possible to increase the reliability of the experimental data, the measurement accuracy and to extend the application area of the dosimetry system using the different operating mode of the dosimeters.

The solid thermoluminescent dosimeters DTL-02 were used as dosimetric equipment. The thermoluminescent material of the detectors is LiF: Mg, Ti [11].

The individual capacitor type dosimeters D-2R designed for the exposure dose measurement of gamma radiation. Detector D-2R is a cylinder with the ionization chamber and two fluoroplastic capacitors (the charging capacitor and the measuring capacitor), located at the ends of the detector [12].

The small size of the storage type detectors affects the accuracy of their indications. To solve this problem, each of them was calibrated with the help of specialized clinical dosimetry system of high accuracy UNIDOS E equipped with a PTW soft X-ray plane-parallel ionization chamber type 23342 (the sensitive volume is 0.02 cm³) and with a PTW Farmer chamber type 30013 (the sensitive volume is 0.6 cm³) [13–15].

The obtained results were allowed not only to evaluate the functionality of each dosimeter, and enter to obtain the correction factors for each of them.

The dosimetric equipment specifications are listed in the Table 1.

Table 1. The dosimetric equipment specifications.

The dosimeter type	Physical principle of the radiation registration	The radiation type of registration	The energy range	The dose range
The dosimeter DTL-02	thermoluminescence	gamma radiation	15 keV – 10 MeV	20 μ Sv – 10 Sv
The dosimeter D-2R	ionization	gamma radiation	12 keV – 1.25 MeV	0.1 mSv – 20 mSv
The plane-parallel chamber type 23342	ionization	soft X-ray	7.5 keV – 70 keV	3 mGy – 30 Gy
The cylindrical chamber type 30013	ionization	photon	30 keV – 50 MeV	0.1 mGy – 1 Gy

3. Results and discussions

The figures 1, 2 show an examples of the dose rate spatial distribution of the pulsed X-ray source at the 30 cm distance and the dose rate spatial distribution of the portable betatron OB-4 at the 100 cm distance [16–17].

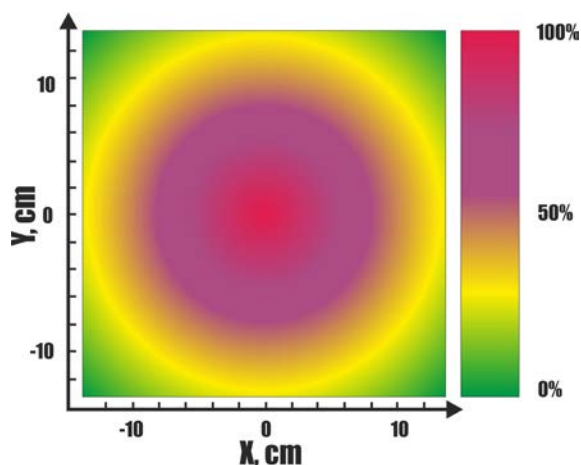


Figure 1. The dose rate spatial distribution of the pulsed X-ray source. Array pitch is 2°.

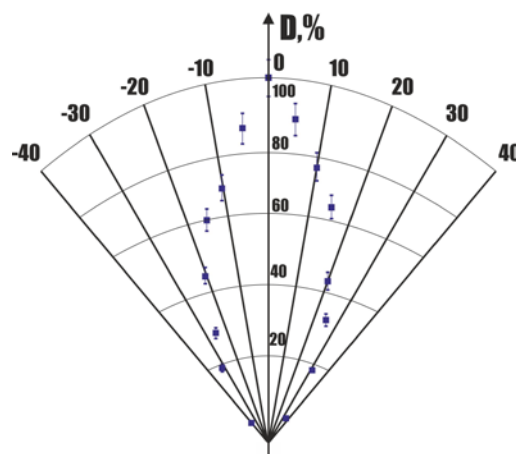


Figure 2. The dose rate profile of the bremsstrahlung generated by betatron.

To calculate the dose rate it is necessary to consider the radiation exposure. However, additional radiation dose on the detectors appearing during the emitting source in the process of stabilization is a problem. The method of calculate the dose received by dosimeter during the time of the source output mode is applied in plants which are not instantaneous get the operating mode [18].

The figure 3 shows a simplified timing diagram of the dose rate of the source at the process of stabilization.

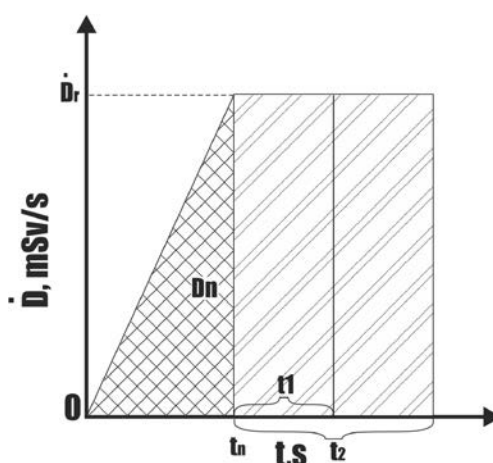


Figure 3. Timing diagram of the dose rate of the source at the process of stabilization.

As it shown in the figure 3, two different exposure times of the dosimeters were chosen. In both cases, total time consists of the output mode time and the operating time of the predetermined mode. The dose received by the detector is the area under the curve of the timing diagram of the dose rate (figure 3). Thus, from the figure 3 that the dose from the time of emitting source in the process of stabilization can be found from the following system of equations:

$$\begin{cases} D_n + t_1 \cdot \dot{D}_r = D_1 \\ D_n + t_2 \cdot \dot{D}_r = D_2 \end{cases} \Rightarrow \dot{D}_r = \frac{D_1 - D_2}{t_1 - t_2} \Rightarrow D_n = D_1 - t_1 \cdot \dot{D}_r = D_2 - t_2 \cdot \dot{D}_r,$$

where D_n – the dose from the time of the emitting source in the process of stabilization;

t_1, t_2 – operating time of the source; \dot{D}_r – the dose rate of the source at the operating mode; D_1, D_2 – the total dose accumulated by the dosimeter during times t_1 and t_2 , correspondingly.

The proposed technique is tested on the dose rate spatial distribution measurements of the several sources of X-ray and gamma-radiation, based on the X-ray tubes, betatrons and linear electron accelerators. The small size of the dosimeters allows to achieve the high spatial measurements accuracy. The obtained correction coefficient for each of the detecting elements is increased the reliability of the measurements.

4. Summary

In this investigation using the proposed method the dose spatial distribution of the different gamma sources, as pulsed and continuous were obtained. The use of different detection elements allows significantly extending the energy range of the registered radiation: from a few keV to a few MeV. To improve the accuracy of the dosimetric system the additional calibration of each individual storage dosimeter was carried out. To improve the reliability of the results the errors associated with the dose accumulation during the time of the source output mode took into account with the help of the developed method.

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).

References

- [1] Kurokawa C and Urushiyama A (2013) Measurements for dose distribution with a photo-stimulated luminescence dosimeter sheet *J. Phys.: Conf. Ser.* **444**(1) 012035
- [2] Cherepennikov Y and Gogolev A (2014) Device for X-ray spectral absorption analysis with use of acoustic monochromator *J. Phys.: Conf. Ser.* **517**(1) Article number 012037
- [3] Low D (2015) The importance of 3D dosimetry *J. Phys.: Conf. Ser.* **573**(1) Article number 012009
- [4] Gogolev A, Stuchebrov S, Wagner A, Cherepennikov Yu and Potylitsyn A (2012) Acoustic “pumping effect” for quartz monochromators *J. Phys.: Conf. Ser.* **357** (1) Article number 012031
- [5] Kaderka R, Schardt D, Durante M, Berger T, Ramm U, Licher J and Tessa C La (2012) Out-of field dose measurements in a water phantom using different radiotherapy modalities *Physics in Medicine and Biology* **57**(16) 5059–5074
- [6] Cherepennikov Y and Gogolev A (2012) Method to reduce radiation exposure in the medical X-ray diagnostics *Proceedings - 2012 7th International Forum on Strategic Technology, IFOST 2012* Article number 6357737
- [7] Operations manual 2008 *Portable X-ray device for the industrial utilization* (Tomsk: Photon) p. 34 [in Russian]
- [8] Service log 2011 *X-ray generator for the technical application* (Tomsk: Photon) p.17 [in Russian]
- [9] Technical specification 2010 *Inductive cyclic accelerator OB* (Tomsk: Betta Plyus) p. 15 [in Russian]
- [10] Egorov I S, Kajkanov M I, Lukonin E I, Remnjov G E and Stepanov A V (2013) The Astra repetitive-pulse electron accelerator *Instruments and Experimental Techniques* **56**(5) 568–570
- [11] Technical specification ZhBIT2.805.006RJe 2012 Thermoluminescent dosimeters DTL-02 (Moscow: Doza) [in Russian]
- [12] Information on <http://www.aes.pp.ua/RSafety/P11-02.htm>
- [13] Information on http://www.ptw.de/unidos_e_dosemeter_ad0.html?&cId=3965.
- [14] Instruction manual 2013 Soft X-ray chamber Type 23342 (Freiburg: PTW) 15 p
- [15] User Manual 2013 Ionization Chamber Type 30010, 30011, 30012, 30013 (Freiburg: PTW)
- [16] Miloichikova I A, Stuchebrov S G , Krasnykh A A and Vagner A R (2015) Dose rate spatial distribution produced by the pulsed X-ray source in the radiographic examination *Adv. Mater. Res.* **1084** 598–601
- [17] Miloichikova I A, Ruchjeva V A, Shuvalov E N and Stuchebrov S G (2014) Depth dose distribution of the bremsstrahlung generated by the betatron OB-4 in different environments *XXIV Russian Particle Accelerator Conference: Proceedings* 266-268
- [18] Miloichikova I A, Stuchebrov S G , Krasnykh A A and Vagner A R (2015) Radiation dose measurement technique of the X-ray source in the process of stabilization *Adv. Mater. Res.* **1085** 478-481