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# Measuring the amplitude-time characteristics of a pulsed high-intensity gamma radiation accelerator Varian Clinac 600C with a CdTe detector

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Measurements of the amplitude-time characteristics of a high-intensity pulsed gamma radiation accelerator Varian Clinac 600C with photon energy from 1 to 6 MeV on the equipment using a CdTe detector in both current and pulse modes have been carried out. It is shown that the operation of the CdTe detector in the current mode allows one to control the frequency of the accelerator pulses, and the operation of the CdTe detector in the pulse mode allows for determining the dose in each pulse with an error of 0.06 %. Monitoring the operation of the accelerator Varian Clinac 600 C shows that the pulses come in batches; within the batch, the pulse repetition period corresponds to a specified frequency at the accelerator, while the repetition period of the batches differs from the specified frequency. Dose control in the pulses showed its 5 % excess over the average value during the first 2.5 s of the accelerator operation, whereas during the last 2 s, the dose reduction by 1.8 % was observed.

**Keywords:** linear accelerator, pulsed gamma radiation, telluride cadmium detector, pulse frequency.

Проведены измерения амплитудно-временных характеристик импульсного высокоинтенсивного гамма-излучения ускорителя Varian Clinac600C с энергией фотонов от 1 до 6 МэВ на аппаратуре с использованием детектора CdTe при работе в токовом и в импульсном режимах. Показано, что работа CdTe детектора в токовом режиме позволяет контролировать частоту импульсов ускорителя, а работа CdTe детектора в импульсном режиме позволяет определять дозу в каждом импульсе с погрешностью 0,06 %. Контроль работы ускорителя Varian Clinac600C показывает, что импульсы приходят "пачками", в которых период их следования соответствует заданной частоте на ускорителе, а период следования "пачек" отличается от заданной частоты. Контроль дозы в импульсах показал ее превышение над средней величиной в первые 2,5 с работы ускорителя на 5 %, а в последние 2 с — ее уменьшение на 1,8 %.

**Вимірювання амплітудно-часових характеристик імпульсного високоінтенсивного гамма-випромінювання прискорювача Varian Clinac 600C детектором CdTe.** *О.М.Григор'єв, З.В.Білик, Ю.В.Литвинов, І.Ю.Чернявський, М.Є.Полянський, В.П.Старенький, І.О.Самофалов, Є.Ф.Воронкін, О.О.Сосницька, С.Ю.Петрухін, Г.М.Сучков, Н.Г.Білик, С.М.Індиков, В.Б.Матикін, С.А.Писарєв, О.В.Матикін, С.М.Меньшов*

Проведено вимірювання амплітудно-часових характеристик імпульсного високоінтенсивного гамма-випромінювання прискорювача Varian Clinac 600C з енергією фотонів від 1 до 6 МеВ на апаратурі з використанням детектора CdTe при роботі у струмовому і в імпульсному режимах. Показано, що робота CdTe детектора у струмовому режимі дозволяє контролювати частоту імпульсів прискорювача, а робота CdTe детектора в імпульсному режимі дозволяє визначати дозу у кожному імпульсі з похибкою 0,06 %. Контроль роботи прискорювача Varian Clinac 600C показує, що імпульси приходять "пачками", в яких період їх надходження відповідає заданій частоті на прискорювачі, а період надходження "пачок" відрізняється від заданої частоти. Контроль дози в імпульсах показав її перевищення над середньою величиною у перші 2,5 с роботи прискорювача на 5 %, а в останні 2 с — її зменшення на 1,8 %.

## *1. Introduction*

Nowadays, high-energy and high-intensity generating installations are widely used in radiation therapy, allowing one to create a planned integral dose for humans. Different modes of operation of the accelerator allow you to fully extend the "radiotherapy interval" by changing the conditions of irradiation: dose options, changing the rhythm and time of irradiation [1, 2]. In these conditions, special attention is paid to the technical and dosimetric aspects of therapy: the monochromaticity of the radiation spectrum, which determines the planned effect; calculation of the dose at different depths and determination of the maximum radiation in the tissue. In this regard, questions about the methods of objective control of the delivered dose, the estimation of errors in the calculated data, the adequacy of the mathematical model of the generated intensity profile of the irradiation field and their optimization come to the foreground. These tasks are being solved as a result of dosimetry in a water phantom, which is a complex, time-consuming and expensive procedure using highly accurate clinical dosimeters UNIDOS along with the ionization chamber. According to [3], objective information can be obtained using specially developed diagnostic systems (DS). These systems are designed to certify (verify) the operating modes of high-energy generating installations in preparation for their intended use; to control the stability of radiation parameters; in measurements of amplitude-time characteristics of irradiation fields in pulses; to determine irradiation irregularities by distribution of the radiation intensity; in diagnostics of the electron beams of the accelerator according to the spectral and time characteristics of the generated bremsstrahlung.

On the other hand, the error in the dose profile in the irradiation field can be determined by instability of the flux intensity and spectral heterogeneity of the photon energy [1, 2]. In our opinion, this is due to the features of the accelerator. The medical linear accelerator constantly needs dosimetric control, control of the spectral and amplitude-time characteristics of the radiation beam. The studies of the dose rate spatial distribution (from 0.6 mGy/min to 0.5 Gy/min) in high-energy installations are known in the literature. In the work [4] the dosimetric characteristics of the pulsed bremsstrahlung of a betatron with a maximum energy of 4 MeV, a pulse frequency of 400 Hz and pulse duration of 15 μs were estimated using the thermoluminescent dosimeters DTL-02. The analysis of the literature has shown that the time intervals between the pulses in the "batches", between the "batches" in the series, as well as the stability of the pulse amplitudes in the linear accelerator Varian Clinac 600C were not investigated. It is possible to investigate these parameters, applying the technique [3] and high-resolution indoor temperature semiconductor detectors [5].

In the literature there are a number of studies on the medical use of the CdTe detector [6–8] and the detection of high-intensity gamma radiation [9–12]. So, in [6], the possibility of using this type of detectors to obtain a three-dimensional dose distribution in real time during the boron neutron capture therapy was investigated. The most complete analysis of the applicability of this detector for medical purposes in the detection of photons in the range of 10–500 keV is described in [7]. The paper [8] includes data that make it possible to directly associate the energy released in the CdTe detector with the dose in the tissue in a wide range of energies of the continuous gamma-radiation field.

Problems associated with high-intensity γ-radiation dosimetry in the energy range of 0.06–1.2 MeV were studied in [9] along with the operational characteristics of the detectors, their temperature stability, reproducibility and reliability of the detector measurements. Also in [9] the time characteristics of CdTe based detectors of SPDD 29 type at the SPIN 2 electron accelerator were studied. In the present paper, the measuring channel time resolution (which should be much better than the time resolution of the detector) was studied by registering the pulses of X-rays — a softer radiation than that used in Varian Clinac 600C accelerators. It should be noted that earlier, the authors of the present paper investigated the linearity of the counting characteristic depending on the dose rate with a CdTe sensor (6×6×3 mm$^3$ in size) for gamma quanta with energy of 662 keV from the $^{137}$Cs sources of various activity [13].

Thus, at the user-defined level, in the Varian Clinac 600C accelerator, only the integral dose is controlled by an ionization chamber located in front of the patient; and the irradiation rhythm is changed in two modes (with a constant frequency between pulses or that between the "batches" of the pulses) which are not controlled by the operator. In this regard, the purpose of the present paper is to create a device and techniques for recording both the amplitude-time characteristics of the gamma bremsstrahlung and the amplitudes of individual pulses during the measurements in the Varian Clinac 600C accelerator, as well as to determine the absorbed dose of the detector in each pulse with high accuracy.

## 2. Materials and methods

According to the technical documentation for the medical linear accelerator Varian Clinac 600C, its bremsstrahlung photon energy range is 0–6 MeV (Fig. 1) with an average energy of about 1.49 MeV [14]. The bremsstrahlung is generated when braking fast electrons in a tungsten target. The photon beam is formed by the MLC VARIAN Medical Systems collimation system, located directly behind the target and the diaphragm, which limits the irradiation field with energy of 1–6 MeV.

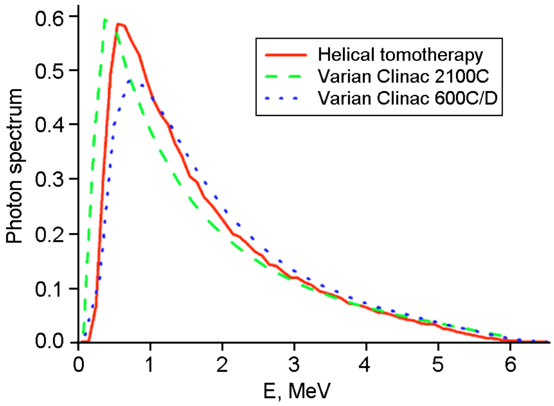

Fig. 1. Spectral distribution of photon radiation from a Varian Clinac 600C [14] linear accelerator.

The accelerator forms a standard rectangular field of 40×40 cm$^2$ at a distance of 100 cm from the focus at the location of the CdTe detector. The symmetry and uniformity of the irradiation field is not more than 1.5 %. The maximum radiation power of the accelerator is 400 MU/min, which corresponds to the absorbed dose rate of 4 Gy/min (6.6 R/s) at the detector location. In the experiment on irradiating the CdTe detector, we used 80 MU/min (0.8 Gy/min). The durations of a single pulse and the pulse repetition period measured by the SDS1000CML/CNL/DL oscilloscope were 3.5 μs and 18 ms, respectively.

Experimental evaluation of the amplitude-time distribution of gamma radiation was carried out by automatically counting the number of pulses with intervals between measurements of 200 μs, using the hardware complex we developed.

The basis of the complex is a computer measuring device — an electronic unit including a four-channel sixteen-bit ADC, a microcontroller, and interface to a computer. The CdTe sensors, 5×5×2 mm$^3$ in size, operating in current and pulsed modes for measuring high-intensity gamma radiation generated by a linear accelerator, are connected to the electronic unit through an amplifier. A peak detector was included in the device for a precise measurement of the amplitude of a single pulse. The instrument with the peak detector was tested using a stabilized ultraviolet radiation source heated for three hours.

At the same time, the noises of the sensors, the amplifier and the ADC channel including the noise of the signal source were 8 units of the ADC. The testing was conducted over 10 s.

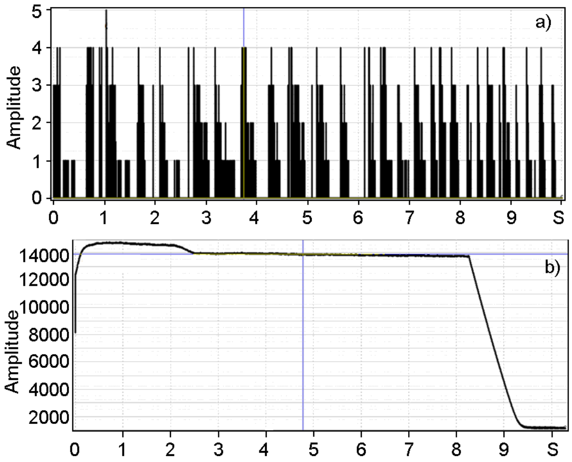

Fig. 2. Amplitude-time distribution of pulses at a dose rate of 0.8 Gy/min during a measurement time of 10 s: a) — operation of the CdTe detector in the current mode; b) — operation of the CdTe detector in the pulsed mode.

## 3. Results and discussion

The CdTe detector in the current mode, together with the ADC, records the amplitude-time distribution of the pulses during the measurement time of 10 s (Fig. 2a), and the same equipment with a peak detector registers amplitudes of individual pulses during the measurement time of 10 s (Fig. 2b) when registering bremsstrahlung with an absorbed dose rate of 0.8 Gy/min.

Analysis of the obtained amplitude-time distribution (Fig. 2a) shows the instability of the amplitude of the pulse inside the "batch" with a given pattern.

This fact is confirmed by the obtained value of the amplitudes of the pulses when the CdTe detector is operated in a pulsed mode with a time resolution of 4 μs (Fig. 2b). The detector with a dose rate of 0.8 Gy/min, which was set by the operator, registered the time distribution of pulse amplitudes; the average of the amplitudes was 14,000 in relative units of the ADC, and the integral dose was 7.84 Gy in 10 s.

With the joint work of two CdTe detectors operating in the current and pulsed modes simultaneously, the obtained pulse amplitudes (Fig. 2b) were compared with the amplitude-time distribution of the pulses (Fig. 2a); then the ratio of the total integral dose during the measurement to the number of pulses was calculated, and the absorbed dose in the sensor for a separate pulse was determined. It is necessary to note that the maximum pulse amplitude during the first 2.5 s is 5 % more than the average, and after 8 s it is 1.8 % less than the average (Fig. 2b), although according to the technical characteristics of the accelerator, the maximum difference in pulse amplitudes should be 1 %. The error of the measuring device with an amplitude of 14750 relative units of the ADC is not more than 0.06 %, which is significantly less than the error of 1 % given in [3, 15].

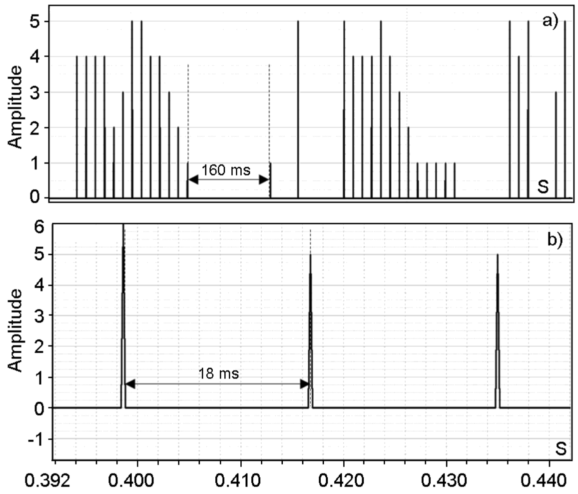

Fig. 3. The amplitude-time distribution of high-intensity pulsed gamma radiation when the CdTe detector is operated in the current mode with a pulse repetition period of 18 ms: a) — the period of the repetition of "batches" of pulses with an average time of 160 ms, b) — the interval of 0.399–0.435 s, which shows the repetition period of 18 ms of pulses in the "batch".

When analyzing the repetition period of "batches" in a series in 10 s, when the CdTe detector is operated in the current mode, it is revealed that it varies from 220 to 55 ms, and the average time is 160 ms (Fig. 3a). The duration of the "batch" of pulses varies from 150 to 230 ms, and is associated with a different number of pulses in the "batch".

An analysis of the pulse repetition rate in the "batch" clearly shows a stable pulse repetition period (Fig. 3b). In this case, all the pulses that come from the accelerator are recorded, since a period of 18 ms is set between them.

Then the increased pulse repetition frequency was set, and the repetition period was 4.5 ms (Fig. 4a). The results showed that there were only two pulses in the "batch" with a repetition period of 4.5 ms at this frequency, and the repetition period of the "batches" in the series is 14 ms (Fig. 4b). The evaluation of the correlations between the pulse repetition periods (18 ms and 4.5 ms), the durations of the "batches" of pulses,

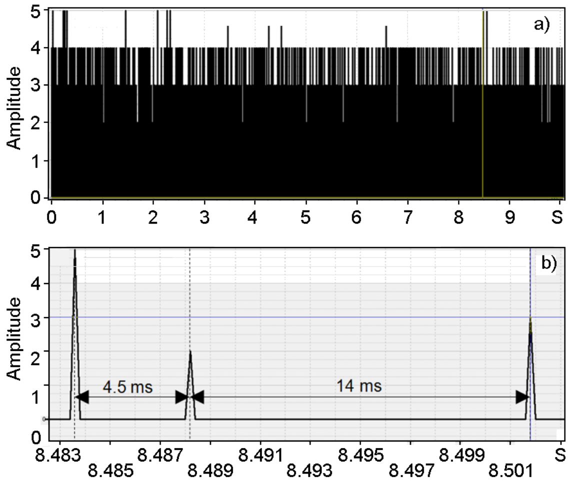

Fig. 4. The amplitude-time distribution when the CdTe detector is operated in the current mode with a pulse repetition period of 4,5 ms: a) — a period of 0–10 s, b) — a period of 8.483 to 8.5003 s. The pulse repetition period in a batch is 4.5 ms, and the average repetition period of "batches" is 14 ms.

and the repetition periods of the "batches " in the series (Fig. 3, 4) led us to conclude that this feature is related to the operating mode of the linear accelerator Varian Clinac 600C. The period of the "batches" was counted from the end to the beginning of the next "batch", since, based on Einstein's formula for the corresponding accelerator gamma radiation energy, the "batches" can be viewed as a series of impacts of a certain mass and frequency.

## 4. Conclusions

Using the developed device, the amplitude-time distribution of high-intensity pulsed gamma radiation with energy of 1–6 MeV from the linear accelerator Varian Clinac 600C was obtained. The results give a possibility to control the dose absorbed by the sensor (at its location) with an error of no more than 0.06 %, both during the whole measurement, and during one pulse. It would be interesting to investigate the dependence of the biological effect of suppressing cancer cells depending on the operation mode of the accelerator, i.e. frequency, duty ration, and amplitude of the pulse of gamma photons.

It is possible to measure the absorbed energy in the patient's body when the CdTe detectors are located on the patient's body surface and under it, which ultimately makes it possible to determine the biological effectiveness of the radiation dose. This fact opens up wide possibilities to use the detectors in creating diagnostic systems for a linear accelerator, in researching gamma-ray bursts in space [16], in recording the amplitude-time characteristics of high-intensity gamma radiation [17], and as well as to use the miniature detectors in subcritical assemblies [18].

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