Frequency Nanosecond Electron Accelerators Type URT

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Abstract – Frequency nanosecond electron accelerators type URT have been developed for use in radiation technologies. The accelerators include a thyratron, a pulse transformer, and a semiconductor opening switch. The accelerating voltage is up to 0.9 MV, FWHM pulse length is up to 50 ns, and the operating frequency is up to 250 Hz. A metal ceramic cathode, which is used in the accelerator, provides an electron beam up to 160 mm in diameter at a maximum density of the pulse current equal to 2 A/cm^2. A vacuum diode has been developed for two-sided irradiation of materials. The cathode holder of the vacuum diode is designed as two symmetric arms, which are connected to a common current conductor and mount two cathodes at the ends one opposite to the other.

The vacuum diode with dielectric metal cathodes was tested in a URT-0.5 electron accelerator (the electron energy being up to 0.5 MeV and the average output power of the beam up to 1 kW).

1. Introduction

In distinction to scientific and military applications, the commercial use of accelerating equipment places first purely consumer properties of accelerators, namely a low cost, fabrication simplicity, ease of maintenance, reliability, and durability. Among a great number of nanosecond electron accelerators, those used the high voltage source based on semiconductor opening switches (SOS) [1–6] answer these requirements most.

Today these accelerators are designed using two ways:

1) circuits for preliminary magnetic compression of energy – SOS;

2) thyratron – pulse transformer – SOS.

The main advantage of the first approach is that a high-voltage pulse is formed in an all-solid-state devices providing a high operating frequency and a long lifetime.

Advantages of the second approach include a relative simplicity of the accelerating voltage formation circuit, which does not contain interconnected stages of magnetic compression of energy. This feature considerably simplifies adjustment and repair of accelerators and makes them suitable for commercial production. Further, the accelerating voltage and the average output power of the accelerator can be adjusted separately.

The main drawback of the second circuit is that it includes a thyratron, which lives much shorter than other components of the circuit. However, a thyratron represents a relatively cheap device, which is manufactured in large quantities. Therefore we think its use has been justified.

The URT-0.2 accelerator [3] served to check serviceability of the chosen circuitry and improve the accelerator setup, which was refined in the URT-0.5 accelerator [4]. However, studies into the use of nanosecond accelerators [7] showed that the electron energy need be increased at no sacrifice of the average power of the accelerator. Therefore, the URT-1 accelerator was developed. Parameters of the accelerators are given in the Table below.

Table. Parameters of URT accelerators

Accelerator	U, kV	Pulse energy, J	T_p, ns	Operating frequency, pps
УРТ-0.2	200	1.75	35	250
УРТ-0.5	500	6.25	50	200
УРТ-1	900	25	50	50(10)

Notice that the developed accelerators of electrons combine a compact size, a simple design, and ease of maintenance.

One more problem, which was solved by development of the URT accelerators, was provision of two-sided irradiation so that irradiation homogeneity is improved and thickness of irradiated items is increased, while the absorbed dose is distributed uniformly over the depth.

Generally, when accelerators of charged particles (including electron accelerators) are used, two accelerators or special systems of beam scanning are installed for two-sided irradiation [8].

However, development of a system for scanning of high-current nanosecond beams of electrons is technically unreasonable and the use of two accelerators is expensive.

All these considerations led to a design employing one generator of high pulsed voltage and two unsoldered nanosecond tubes [9] located on opposite sides. Despite its advantages, this approach causes a considerable stray capacitance of the high-voltage splitter because of liquid insulation of the high-voltage electrode, which reduces the accelerating voltage amplitude.

2. Design of the Accelerators

Let us consider the design and operation of the accelerators taking the URT-1 accelerator as an example. A distinctive feature of the URT-1 accelerator circuitry (Fig. 1) was that the forming inductor comprised not only self-inductance of the reverse pumping circuit of SOS (as in [3, 4]), but also an additional magnetic coil, whose inductance (L = 6.4 μH) was optimized experimentally. The additional magnetic coil was intended to decrease the effect of SOS nanosecond pulses on insulation of the pulse transformer (PT).

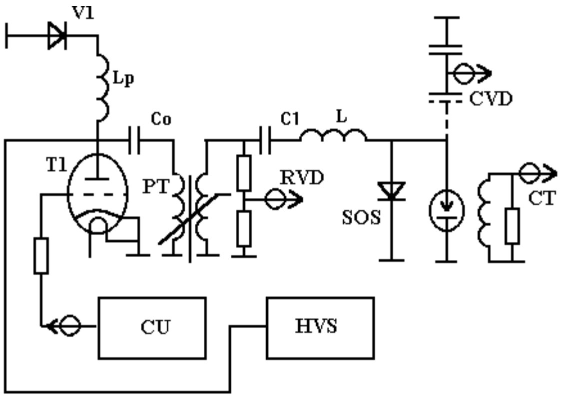

Fig. 1. Circuitry of the URT-1 accelerator

PT was wound on a core comprising three rings K650×470×25 mm^3 (20 μm thick) made of the 50NP permalloy. The transformation ratio was 10, while the leakage inductance was about 1 μH. The windings were made of a copper tape 0.5 mm thick. Tapes of the secondary and primary windings were 30 mm and 50 mm wide respectively. The primary winding overlapped nearly one-third of the secondary winding, which was wound on an acrylic-resin framework. Insulation gaps between the core and the winding and between the windings were 25 mm wide.

Magnetization of the pulse transformer core was reversed efficiently using a recovery circuit, which included a diode V1 (SDLK 0.4/125) and an inductance coil (L_p = 20 μH). The recovery circuit considerably improved stability of the accelerator, especially in the single pulse regime.

Capacitance of the first circuit was rated at C_0 = = 57.5 nF. By design, it consisted of 48 parallel sections each comprising five series-connected capacitors type KVI-3-12kV-6800pF. Capacitance of the second circuit was rated at C_1 = 425 pF. By design, it included 3 parallel sections each comprising 36 series-connected capacitors of the same type.

Thyratron T1 with a TP2-10k/50 type with a cold cathode [10] operating under earthed cathode conditions was used for switch on.

SOS included 4 parallel branches of seven series-connected diodes type SDLK 0.4/125. The high-voltage pulse circuit and the vacuum diode were immersed in transformer oil in a square-section metal tank 900 mm wide and 1300 mm high having a water cooling jacket on the top.

The high-voltage source (HVS) converted the 220-V mains voltage to a regulated constant voltage of up to 50 kV. The accelerator was operated remotely from a control unit (CU).

The vacuum diode of the accelerator operated at a pressure of about 10^{-4} Torr, which was produced by a diffusion vacuum pump type N-100.

The vacuum diode was tested with metal dielectric (MDM) [11] and metal ceramic (MC) [12] cathodes. The beam left the vacuum diode through an outlet window 170 mm in diameter.

Voltage at the vacuum diode was measured using a capacitive voltage divider. The electron beam current at the outlet from the vacuum diode was measured by the current transformer in the anode flange. A Tektronix TDS 360 digital oscilloscope recorded electric pulses.

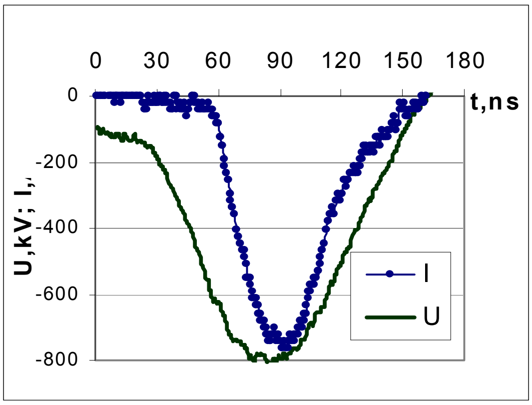

Fig. 2. Oscillograms of the beam current (I) and the vacuum diode voltage (U) at the anode-to-cathode distance d = 90 mm

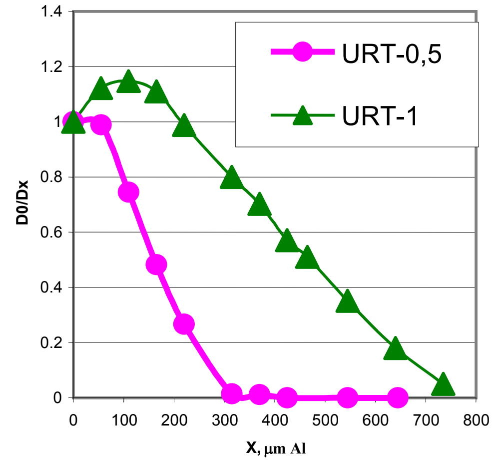

Fig. 3. Distribution of the absorbed dose in Al for URT-0.5 and URT-1 accelerators

Functioning of the vacuum diode for two-sided irradiation (VDTSI) was tested experimentally in a URT-0.5 accelerator [4]. To this end, the usual diode of the accelerator was replaced by VDTSI (Fig. 4). The casing had two opposite ports-anodes for transmission of a beam 100 mm in diameter. The left- and right-hand cathode holders were made of duralumin rods 40 mm in diameter. By design, the cathode holders allowed adjusting both distances between the cathodes and the anodes (d_1 and d_2). The cathode holders were attached to the common current conductor such that the cathodes could be aligned in the outlet windows. MDM cathodes, which were analogous in design to those used in [4], were used in the experiments.

The vacuum diode of the URT-0.5 accelerator operated at a pressure of about 10^{-3} Torr, which was produced by a rotary vacuum pump type AVR-50.

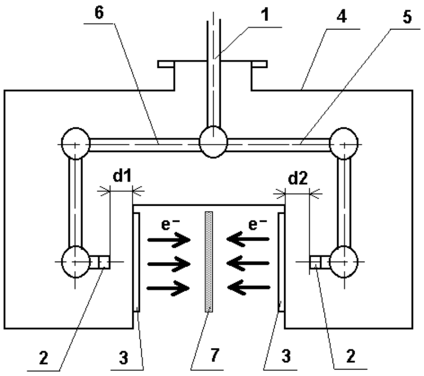

Fig. 4. Design of the vacuum diode of two-sided irradiation

A dosimeter method [3] was used to measure irradiation characteristics and check results of electric measurements for the URT-1 accelerator and VDTSI. The absorbed dose of the electron beam at the outlet of the vacuum diodes was measured by dosimeter films type CDP-2-F2 [13]. The detectors were installed on the outside closely to the outlet foil. The size of the detector provided a full pattern of the beam, which was processed in an IFO-463 densitometer after exposure. Therefore, it was possible to determine the absorbed dose distribution and, consequently, the density of the electron current over the beam cross-sectional area. Measurements were made over 10 pulses generated at a frequency $f = 1$ Hz.

In addition, detectors were placed behind aluminum foil layers of different thickness to determine the absorbed dose distribution over the depth of the material.

3. Experimental Method and Results

The URT-1 accelerator achieved the following performance values: the accelerating voltage of up to 900 kV, FWHM current pulse duration $t_p = 50$ ns, and the continuous operation frequency up to $f = 10$ Hz (determined by the capacity of the high-voltage source).

Characteristic oscillograms of the beam current (I) and the vacuum diode voltage (U) at the anode-to-cathode distance $d = 90$ mm are given in Fig. 2.

Figure 3 presents dosimeter data for the URT-0.5 and URT-1 accelerators. The electron energy measured by the dosimeter method was a little higher (0.9–1 MeV) than the one obtained in the electric measurements. This fact was due probably to a relatively large inductance of the vacuum diode (the total length of the cathode holder was ~70 cm).

The VDTSI operation was analyzed both at an equal cathode-to-anode distance $d_1 = d_2 = 90$ and different distance ratios. It was found that amplitudes of the accelerating voltage and the full current of the beam decreased a little, while the pulse length (t_p) increased as compared to the operation of the URT-0.5 accelerator with one vacuum diode (the left-hand cathode was removed in this regime). The increase in the pulse length was due to the fact that $t_p \sim L_{\text{store}}/R_d$ when pulses were formed in circuits with an intermediate inductive storage. In other words, when the two-sided diode was used, the storage inductance L_{store} remained unchanged, while the sum impedance of the vacuum diodes R_d (which were connected in parallel) decreased almost twice.

Calculation, which was made using the size of the beam pattern and the density of the electron beam current (estimated by the method [3]), showed that the decrease of the distance d in one of the diodes did not cause a redistribution of the current between the cathodes. The increase in the absorbed dose at the anode was the greater, the smaller d was. However, this was due to the geometrical factor related to the decrease in the beam diameter. As a result, the anode current density, which was directly proportional to the absorbed dose, increased. The beam prints were similar when the anode-to-cathode distances were equal.

Measurements of the absorbed dose distribution in aluminum showed that the form of the depth distribution at $d_1 = d_2 = 90$ mm differed from the one obtained in the single-cathode regime (Fig. 5). This observation was in favor of VDTSI. Notice that the diodes did not misoperate at any combinations of d_1 and d_2.

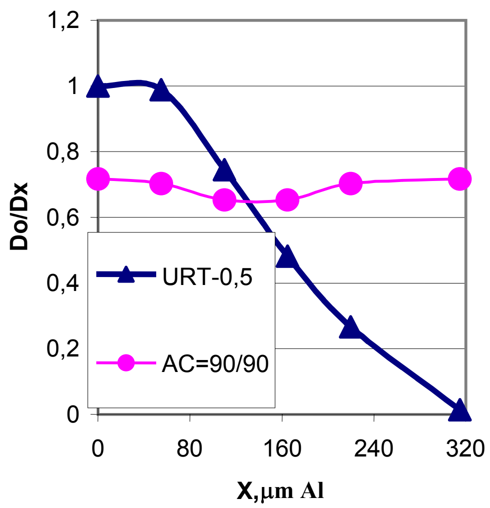

Fig. 5. Distribution of the absorbed dose in the depth of the material for the URT-0.5 accelerator in the case of one-sided irradiation (the anode-to-cathode distance is 90 mm) and two-sided irradiation ($d_1 = d_2 = 90$ mm)

The VDTSI performance was experimentally checked in a URT-1 accelerator. A patent covering the VDTSI design is pending.

4. Conclusion

Thus, a family of nanosecond electron accelerators has been developed for use in radiation technologies applied to layers up to 0.4 g/cm^2 thick, such as radiation sterilization and radiation treatment of thin liquid layers and loose materials, and stimulation of chemical reactions in gas precursors.

The new vacuum diode for two-sided irradiation extends applications of the URT accelerators. Radiation homogeneity of materials is considerably improved and, consequently, the accelerator capacity is largely increased, while the power consumption remains unchanged. A URT-1 accelerator with VDTSI has been installed in a line for sterilization of medical garments, which is currently constructed at "Zdravmedtekh" JSC (Kamensk-Uralsky).

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