Parameters of the Electron Beams Generated by the РАДАН-220 and РАДАН-ЭКСПЕРТ Accelerators


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Abstract—The measured parameters of the electron beams generated by small-sized nanosecond direct-action РАДАН-220 and РАДАН-ЭКСПЕРТ accelerators are presented. The measuring techniques and the designs of electron detectors developed for this purpose are described. The fluence of electrons and the energy density, uniformity, and energy spectrum of the electron beam have been measured.

The РАДАН-220 and РАДАН-ЭКСПЕРТ accelerators developed by the Ural Division of Russian Academy of Sciences’ Institute of Electrophysics (Yekaterinburg) [1] are small-sized high-current direct-action facilities based on explosive electron emission. These accelerators are employed in electrophysical, radiation, and luminescent studies. In particular, the РАДАН-ЭКСПЕРТ accelerator (see Fig. 1) is used to initiate pulsed cathodoluminescence in the КЛАВИ analyzer of substances [2]. The accelerators are based on switched-mode power supplies composed of a high-voltage unit with a sealed-off ИМАЗ-1503 accelerating tube, a power supply, and a control unit. The main performance characteristics of these units are presented in Table 1.

The accelerators’ high-voltage unit comprises a switched-mode power supply on the basis of a resonance open-core transformer (Tesla’s transformer) combined with a coaxial forming line. Such power supplies have high efficiency and allow squared pulses to be generated while maintaining a low level of electromagnetic noise.

Measuring the electron beam parameters is a rather complicated task. To perform it, special electron detectors and measuring techniques were developed by All-Russia Research Institute of Technical Physics (Snezhinsk). In this paper, we present the results of these development works and the measurements of the electron beams ejected into air.

Energy spectrum of the electron beams. The energy spectrum of electron beams was determined using a combined experimental and computing method. This method consists in measuring the energy deposition (absorbed dose) profile in a homogeneous material, computing the energy deposition profiles in this material for monoenergetic radiation, and reconstructing the energy spectrum by means of mathematical processing.

The energy deposition profile was measured by the acoustic method [3]. The detector used in our experiments was composed of a striker (a magnesium disk 60 mm in diameter and 3 mm thick), a quartz gauge 10 mm in diameter and 0.3 mm thick, and an acoustic load (a copper disk). The striker, the gauge, and the load were forcibly pressed to the detector base, and vacuum oil provided acoustic contact between them. The spacing between the accelerator’s exit window and the striker’s surface was 5 mm. A current pulse from the quartz gauge, the amplitude and timing parameters of which are an electrical analog of pressure wave P(t) generated in the striker by the electron beam, was...
detected on a load of 50 Ω using a TDS-3052 digital oscilloscope with a passband of 500 MHz.

Under instantaneous irradiation (when the duration of the electron impulse is much shorter than the acoustic relaxation time), the acoustic response to the irradiation (the pressure wave shape) is known to copy the energy deposition profile for this material [3], the spatial distribution of which is governed by the energy spectrum of the electron beam. This allows the electron energy spectrum to be computed from the pressure pulse shape using currently available reconstruction techniques.

The energy $W_i$ that is absorbed in the $i$th layer of magnesium is related to the electron energy spectrum by the expression

$$W_i = \int_{E_{\text{min}}}^{E_{\text{max}}} f(E) G_i(E) dE, \quad i = 1, \ldots, N, \quad (1)$$

where $f(E)$, electron/keV, is the differential energy spectrum of the electron beam; $G_i(E)$, keV/electron, is the energy deposited by an electron with energy $E$ in the $i$th layer; and $N$ is the number of layers in which the energy of the electron beam is totally absorbed. The energy $W_i$ absorbed in the $i$th layer is proportional to the mechanical impulse generated in the striker and is determined by integrating the spatial distribution (including the velocity of sound in the striker $c_s$) of the pressure wave $P(x) = P(t_c)$ of the energy deposition profiles in the magnesium were computed with a step of 15 μm.

The spatial energy distribution was used as a basis to determine the energy spectrum of the electron beam. With this aim in mind, the profiles of the electron energy absorbed in the MA14-grade magnesium ($\rho = 1.81 \text{ g/cm}^3; \ Z = 24.3$) were computed by using the numerical simulation method for ten single lines of 20–200 keV (with a step of 20 keV) and two single lines of 300 and 400 keV. The absorbed energy profiles were computed for the case where the energy beam was incident at a right angle on an endless plate (i.e., the edge effects were ignored). Using the results of these computations, we determined the matrix representing the spatial distribution of electron energy $G_i(E)$ in magnesium layers with thicknesses varying with a step of 15 μm.

To find the electron spectrum $f(E)$, it is necessary that system (1) of integral equations, the left-side members of which are determined with an accuracy $\Delta W_i$, be solved. This problem falls into the category of ill-posed problems, which is attributable to the limited number of layers, the smoothing action of kernel $G_i(E)$, and the errors of measurements. The energy spectrum of the electron beam was reconstructed using the maximum generalized entropy method [4, 5]. The correctness of the reconstruction was assessed by the average residual (nevsr) from the results of calculation ($W_i$) and experiment ($W_i$) in comparison to the absolute rms error of experiment ($\Delta W_i$). The value of the residual was calculated according to the formula

$$\text{nevsr} = \frac{1}{N} \sum_{i=1}^{N} \left( \frac{W_i - W_i^*}{\Delta W_i} \right)^2. \quad (2)$$

In compliance with the rules of mathematical statistics for random independent quantities ($W_i$) distributed according to the normal law, the values nevsr were considered to be acceptable if they satisfied the inequality

$$\text{nevsr} \leq 1 + \sqrt{2/N}. \quad (3)$$

The results from reconstructing the electron spectra of the РАДАН-ЭКСПЕРТ and РАДАН-220 accelerators are shown in Figs. 2a and 2b, respectively. It is evident from the figures that each energy spectrum has three peaks. The average electron energy is 0.128 MeV for the РАДАН-ЭКСПЕРТ accelerator and 0.168 MeV for the РАДАН-220.

The energy density of the electron beams was determined using two independent methods. The average energy densities inside a 10-mm-diameter circle around the beam axis of the РАДАН-ЭКСПЕРТ and