A CONTROL SYSTEM OF A SCANNING ELECTRON PULSED BEAM FOR AN INDUSTRIAL LINAC

G.F. Popov, A.I. Kalinichenko, and Yu.A. Kresnin
Kharkiv State University, P.O. Box 60, Kharkiv 310052, Ukraine

Abstract

This paper describes a method and a control system of a scanning electron and a bremsstrahlung pulsed beam for industrial linac. The system uses ultrasonic emission generated by the beam in thin rods and plates, as a source of primary information about the current characteristics of each electron/bremsstrahlung pulse. The results of the uniform radiation field forming are discussed.

1 INTRODUCTION

At present scanning electron/bremsstrahlung beams are used in various branches of radiation engineering such as medical and pharmaceutical products sterilization, food and agricultural products radiation treatment, polymer composites manufacturing, electronic components processing, waste utilization, etc.

The scanning beams have some features that obstruct the utilization of conventional dosimetry methods. Each following pulse of electron flux change its attitude. The pulses are characterized by a large spread in parameters, the scanning is accompanied by extended level of electromagnetic interference.

To provide the most effective utilization of the scanning beams it's necessary to develop reliable methods of beam control in real time. Radiation-acoustic effects make it possible to develop such methods.

As it is known, the thermoelastic waves generated in the matter by pulsed radiation carry the information concerning some important radiation and matter characteristics [1],[2]. In recent years, the radiation-acoustic effects have been widely used in dosimetry of pulsed electron beams[3],[4], in express-analysis of material characteristics [5], [6], in electron accelerator control systems [7], etc.

The following specific features of the thermo-acoustic dosimetry method should be of interest for specialists:

1. *High informativity*. The method permits determining the following integral and differential beam characteristics: intensity, total energy, location, duration and radius of the beam; a dose profile formed by radiation in a target; transversal beam current density; time dependence of the beam current; beam energy spectrum.

2. *High sensitivity and high radiation tolerance.* Radiation-acoustic detectors record the acoustic stress from the level of piezoceramic thermal noises, i.e. $\Delta\sigma \approx 0.5Pa$ while detecting at frequencies $\leq$ 5 MHz up to material strength limit, which for the impact forcing of solids makes $\sigma_d \approx 1Gpa$. The corresponding range of the electron flux densities is from $j_{min} \approx 2\Delta\sigma/(\Gamma\chi) \approx 10^5$ electrons/cm^2/pulse up to $j_{\max} \approx 2\Delta\sigma/(\Gamma\chi) \approx 10^{15}$ electrons/cm^2/pulse. Here Γ is the Gruneisen parameter and χ is the ionization energy loss of electrons in target material.

3. *High spatial resolution* of the thermo-acoustic dosimetry is determined by the upper limit of the frequency pass band of the acoustic waveguide. Utilization of wide-band detectors and materials with low acoustic attenuation permits a spatial resolution of acoustic dosimetry up to 0.05 cm.

4. *High noise stability* due to time delay between the moments of accelerator release energy and acoustic pulse registration.

5. *Low-frequency band of acoustic signal.* This feature can be useful for signal processing of nanosecond electron beams.

A few sensitive thermoacoustic dosimeter elements on the base of thin rods and plates were used in the control. The main goal of the control system is to provide of continuous, nondistorting, and highly-informative monitoring of the extensive area under pulsed radiation.

2 SYSTEM CONFIGURATION

A schematic diagram of the radiation facilities is shown in Fig. 1. The radiation facilities consist of a pulsed electron beam accelerator, an electromagnetic scanner (ES), irradiated target (T), an accelerator control system (ACS), scanner control system (SCS), a beam monitor system (BMS), a synchronization module (SM), a CAMAC crate (CC), and an IBM PC with corresponding software.

A linac of the type "Electronica - U003" was used with the following characteristics: electron energy 5-8 MeV; electron beam current 0.5 mA; mean beam power 5 kW; pulse duration 1-4 μs; pulse frequency 1-250 Hz; scanning frequency of electromagnetic scanner 1-8 Hz; the deviation angle of the scanning electron beam was within $\pm 20^o$; the irradiation is possible both with electron and bremsstrahlung beams. The bremsstrahlung radiation was generated by an electron beam in a tantalum converter which was placed in front of the container.

Control of the scanning electron/bremsstrahlung pulsed beams includes joint operation of ACS, SCS and BMS.

ACS is connected to the accelerator power source APS, which consists of a high-voltage source, a modulator, a magnetron, a phase shifter, an electron injector and other elements.

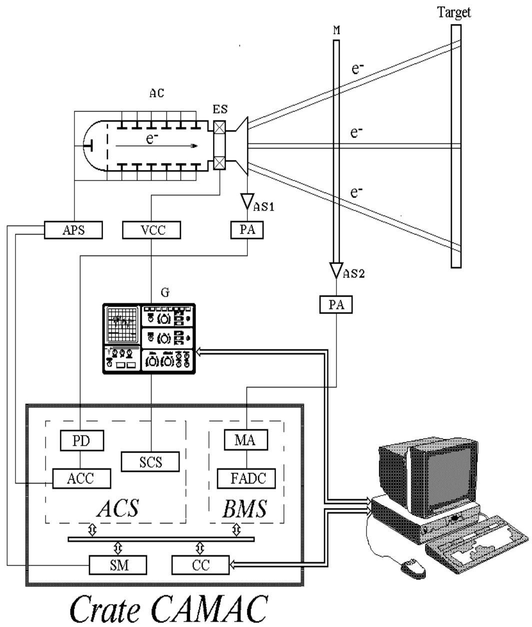

Fig. 1. Block diagram of the radiation facilities.
e^- - pulsed beam of electrons; ES - electromagnetic scanner; M - scanning electron beam monitor; AS1 - acoustic sensor; PA - preamplifier; MA - main amplifier; DCA - direct-current amplifier; FADC - fast analog-to digital converter; SM - synchronization module; ACS - accelerator control system; APS - accelerator power source; ACC - accelerator control console; SCS - scanner control system; VCC - voltage-to-current converter; G - pulsed generator; BMS - beam monitor system; PD - peak detector; CC - CAMAC crate controller.

The SCS is connected to a pulsed generator G, to a voltage-to-current converter VCC, and to an electromagnetic scanner ES. The spatial profile of the radiation field j_e along the irradiated target depends substantially on the form of the current pulse on the deflectors of the scanner ES formed by the pulsed generator G. For in-line check and programmable regulation of j_e, the variation of the generator pulse form is controlled by a PC.

The BMS connected to the thermoacoustic one-dimensional or two-dimensional monitor M based on thin rods or plates as its sensitive elements with a piezoelectric detector AS2 on its butt-end, an electronic preamplifier PA, and an amplifier MA.

Acoustic sensors AS1, PA and PD serve for emergency protection of the accelerator beam-transport pipe against damage from from high-current beam. When the acoustic signal amplitude exceeds a preset limit, the accelerator injector is disabled.

The software is designed a) to control the spatial profile of the radiation field j_e on-line, b) to process and display thermoacoustic signals generated during beam-material interaction and to extract information about each pulse of radiation, to calculate two- and three-dimensional dose profiles in the target material, c) to support the optimal mode for electron and bremsstrahlung beams, d) to control the CAMAC crate modules.

3 CONTROL SYSTEM OPERATION

A number of wire and plate dosimeters were designed and examined experimentally in the control system of the scanning electron pulsed beam for the electron accelerator of the Kharkiv State University. The simplest of them is shown in Figure 2. It was made of wire of 1 to 4 mm in diameter and formed as a straight-line segment. Its working bordy was placed in the normal cross-section of the electron beam. The wire diameter d, as well as its material, was chosen from the condition $d << \min\{D, E_e/\chi\}$, to provide nondistorting dosimetry. Here E_e is electron energy.

When a sequence of electron pulses passes through the rectilinear body of a dosimeter, a sequence of thermoacoustic waves appears in it. In the approximation of instantaneous heating $\tau_b <<$ *D/s* the stress wave amplitude $\sigma(t)$ generated in the dosimeter body by each electron pulse is proportional to the spatial distribution of the absorbed energy. The sequence of the thermoelastic waves goes to a wide-range piezoelectric detector, transforms into electric signals and is displayed by a register device operating in accumulation mode.

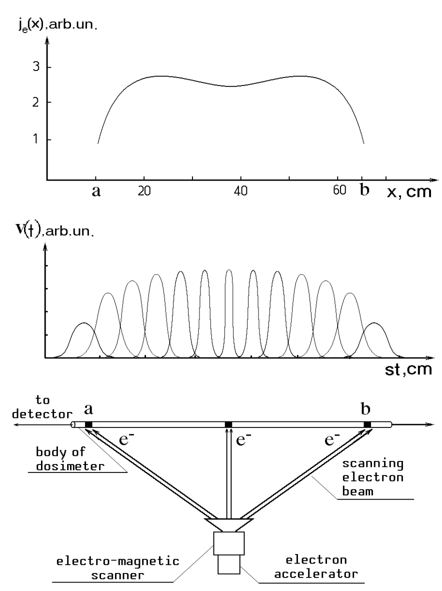

Fig. 2. Utilization scheme of a wire acoustic dosimeter for monitoring of a scanning electron beam. The current in the scanning magnet had sinusoidal form.

Each of acoustic the pulses generated in the dosimeter body by the accelerator pulse sequence carries information about the location and the transverse distribution of a corresponding electron pulse. Registration and processing of the output signal was executed by the BMS. As a result, a spatial profile of the radiation field j_e, caused by any periodic shape of current in the scanning magnet ES, was displayed immediately (see Fig. 2).

The control system permits fitting the profile j_e, to a desirable shape by varying the shape of current in the scanning magnet with help of a pulsed generator G controlled in automatic mode by PC, a voltage-to-current converter VCC, and a scanner control system SCS.

A modification of the dosimeter described above which is capable of realize two-dimensional scanning is shown in Fig. 3**.** Its body consisted of a few parallel 140 cm long titanium wires.

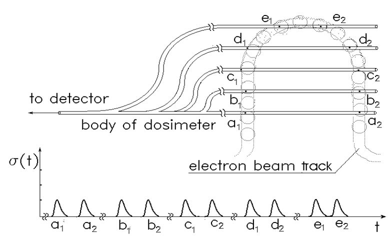

Fig. 4**.** A dosimeter with the ramified body. Acoustic delay between the different branches permits to separated acoustic signals from each branch and to determine the location of the generation zone and dose value in it.

The extreme simplicity of the thermoacoustic dosimeters allows to combine them with other elements of the radiation facility. For axample, a bremsstrahlung converter made of tantalum plate can be utilized as an acoustic dosimeter. Electron beam from the linac with electron energy E_e=7 MeV, passing through the scanning magnet, is directed onto the converter plate which is placed normally to the incident beam. As a result, the scanning bremsstrahlung beam is generated, which is used in many processes of radiation technology. At the same time the primary scanning electron beam generates a sequence of two-dimensional acoustic waves in a tantalum converter. Two acoustic detectors register acoustic signals.

Dosimeters based on one-dimensional and two-dimensional thin targets do not change beam parameters significantly, thus permitting nondistorting acoustic dosimetry of pulsed electron/bremsstrahlung beams.

The developed system allows to measure the following integral and differential characteristics of the beam: intensity, spatial beam disposition on a target, beam size and operation time of the beam, beam current history, longitudinal and transverse distribution of beam particles, energy characteristics, spatial profile of radiation field.

4 CONCLUSIONS

A control system with a thermoacoustic dosimeter can carry out continuous, nondistorting, and highly-informative monitoring of an extensive area under pulsed radiation by a single acoustic detector or a few detectors. During monitoring, both transversal and longitudinal particle distributions of the electron beam, as well as beam location and duration were determined. Such a dosimeter can have the form of a thin rectilinear rod, a bunch of rods, a thin plate, or another form which is defined by the configuration of the area under monitoring.

A control system with wire dosimeters was designed and examined experimentally at the electron accelerator of the Kharkiv State University. The system was used for monitoring of the scanning electron beam in a technological process of radiation-chemical modification of polymer composite materials [8].

The system permits varying of the spatial profile of a radiation field on an extensive target as desired.

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