A BEAM MONITORING & CALIBRATION SYSTEM FOR HIGH-POWER ELECTRON LINACS

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Abstract

Electron beams application in research and technology requires a strict control of main irradiation parameters: electrons energy, beam amplitude and power, as well as absorbed dose in a worked-up material. To provide a certification of accelerators and technologies using electron or bremsstrahlung irradiation a beam-calibration system is elaborated. It consists of a number of primary transducers (combined calorimeter - Faradey cup, Rogovski coils, full-absorption calorimeter for a scanned electron beam, ionization chambers, radiation-acoustic line etc.) provided with suitable electronic setups. PC is used for a data processing. The report describes a method of irradiation-transducer-interaction computer modeling as well.

INTRODUCTION

An “Accelerator” scientific research establishment, affiliated with the National Science Center KIPT, is a leading organization in Ukraine for electron linacs development and construction, including technologies on their base [1]. The establishment also has a number of radiation technology dedicated facilities based on utilization of electron and bremsstrahlung radiation fluxes [2]. Several measurement channels have been developed to exercise control over output radiation parameters. “Accelerator” Establishment, jointly with Kharkov Metrology Institute and Mendeleev Metrology Institute (St.Peterburg, Russia), have developed a reference measurement complex to be need for determination of basic parameters of electron and bremsstrahlung radiation in the electron energy range 5...50 MeV. This energy range choice warranted by the promise of advanced applications (sterilization, semiconductor- and polymeric materials modification, including production items on their base, rubber waste utilization, nuclear medicine radionuclide production, activation analysis, non-destructive testing, etc.). This communication describes measurement instruments for irradiation monitoring & calibration and their performances.

1 BASIC MEASUREMENT DEVICES

A list of main measurement instruments, used for calibration of technological measurement channels is given in Table 1. Below, one can find more detailed of the measurement instruments and results of their metrological studies.

Table 1. Basic Measurement Instruments & their Characteristics

Item No	Measurement instrument	Physics-quantity unit of measurement	Metrological value	Note
1	**2**	**3**	**4**	**5**
1.	Integrated calorimeter- Faraday cup ICFC-2	Energy flux, W	$10^2..10^4$	Unswept electron beam
		Energy flux density, W/m^2	$10^5..10^9$	
		Electron flux, s^{-1}	$10^{12}..10^{15}$	
		Electron flux density, m^{-2}s^{-1}	$10^{15}..10^{18}$	
		Mean electron energy, MeV	5...30	
2.	Electron radiation calorimeter ERC-1	Electron radiation energy flow, W	$5\cdot10^2..10^5$ E_e = 4..12 MeV	Swept (scanned) beam
3.	Magnetic analyzer	Electron radiation energy spectrum in the electron energy range, MeV	6...20	

Table 1(continuation)

1	2	3	4	5
4.	Pulsed current precision reference coil	Pulsed current, A at pulse width	0.25...2.0 τ=4 μs	
5.	e^--radiation calorimeter of absorb. dose - ERC-2	Absorbed dose value, Gy/s	$2 \cdot 10^1$.$2.5 \cdot 10^4$	
6.	Thick wall ionization chamber ICV-6	Energy flux, W Energy flux density, W/m^2 of photon incident irradiation with photon energy, MeV	10^{-4}...20 $5 \cdot 10^{-2}$ .10^6 1...50	

1.1 Integrated calorimeter - Faraday cup

The transducer ICFC-2 is a vacuum pumped Faraday cup with an optimized content and geometry of the active volume in order to decrease the leakage of charge and energy by secondary emission out of the active volume in the incident electron beam energy range 5...30 MeV.

At present, R&D is being carried on to optimize further its geometry with the aim of decreasing its charge dissipation and beam energy losses for E_e up to 50 MeV without deterioration of weight-size characteristics of the active volume.

1.2 Beam energy spectrum magnetic analyzer

A general type of automatic beam energy spectrum analyzer (see fig.1) has been developed for measurement - taking of beam energy characteristics, based on electromagnet **M**, at the exit of which a slit collimator **K** and the Faraday cup are placed, and a magnetoinductive beam current transducer (**MIT** - Rogovski coil), positioned in front of the electromagnet.

By external command IBM PC assigns to the digital-analog converter (**DAC**) a digital code, using which at the exit of the latter there is formed a code-assigned voltage, converted into magnetizing coil current by the V-I converter (**V-IC**). The current value is monitored by the resistor **R1,** and via the normalizing amplifier (**NA**) NA1 and the analog-digital converter (**ADC**) ADC1 it enters PC as a digital code. Simultaneously, a digitized Faraday cup (**FC**) current pulse is fed from FC to PC via NA2 and ADC2,corresponding to the given current value, flowing through magnet winding **M** (to which, in turn, corresponds the given energy value of beam electrons hitting the FC) together with the digitized beam current pulse, obtained from MIT via NA3 and ADC3. Processing the incoming signals according to the assigned program, PC yields, wherever necessary, either a 3-D beam spectrum $I(E_e,\tau)$, where τ is the time space within beam pulse duration, or a $I(E_e)$ spectrum integrated over τ.

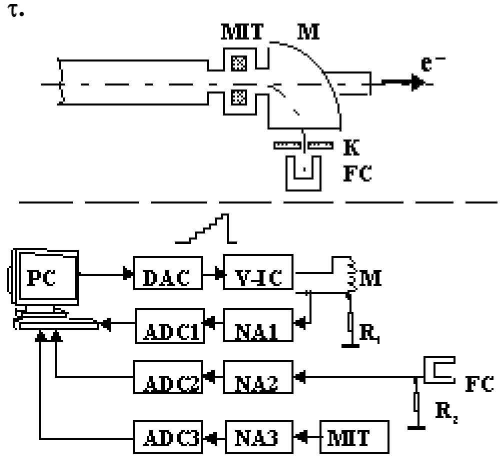

Fig. 1. Magnetic analyzer schematic

1.3 Total absorption calorimeter ERC-1

In order to measure the energy flux (power) of the scanned electron beam a transducer has been developed and constructed as a distilled water-cooled total absorption calorimeter ERC-1 [3].

The calorimeter ERC-1 measurement array includes a built-in turbine transformer of cooling water consumption and two platinum heat resistors, used to measure its temperature at the entrance and exit of the absorber, respectively. Determination of these parameters allows to measure the scanned electron beam energy flow.

This calorimeter ensures beam power measurements with the error, not exceeding 3%.

1.4 Calibration system of the magnetoinductive transducers (MIT) for pulsed beam current

As known, many accelerators have a built-in transducer of the Rogovski coil type, used to take beam current measurements in the beam continuous diagnostic set. For their calibration a system had been developed. The basic constituents of the system are a precision amplitude generator (**PAG**), a two-channel linear switch (**LS**), an ADC and a PC. The PC assigns to PAG the pulse repetition rate and amplitude (at 8 levels). Using LS, the ADC records the PAG pulse shape in sequence, employing a two-page memory, as well as a shape of the pulse at the MIT exit, measured from the load resister $\mathbf{R_L}$. The PC, than, performs their correlation analysis and yields the transducer calibration results. It takes not more then 10 s to run the entire procedure.

1.5 Absorbed dose calorimeter

By implementation of radiation technology processes, involving electron and bremsstrahlung radiation as working devices for measuring the absorbed dose in the range 4...150 kGy, usually requires employment of solid optical dosimeters, ensuring operation with an-error ±15%. To calibrate them the reference absorbed dose calorimeter ERC-3 was developed and constructed in 1994. Its operation principle is based on measurements of the radiation absorbed energy in the active volume, (a graphite pellet, 20 mm in diameter and 2 mm thick under the conditions of electron equilibrium). This accomplished, irradiation of the calibrated dosimeters is performed in the same conditions. As metrological studies showed, the calorimeter ERC-3 ensures measurement of the electron radiation absorbed dose in the dose power range $2 \cdot 10^1$- $2.5 \cdot 10^4$ Gy/s with the error not more than 5%.

1.6 Ionization chambers

Calibration of bremsstrahlung radiation measurement instruments over energy flux (power) is performed, using the reference thick-wall ionization chamber ICV-6, developed and constructed by Mendeleev Metrology Institute. The chamber ensures measurement accuracy, not worse then 10%. For metrological monitoring of radiation processes in the narrow bremsstrahlung radiation beams the above Institute has built a thin-wall ionization chamber-observer IC-O.

2 TECHNOLOGICAL RADIATION - CONTROL CHANNELS

A predominant part of the existing radiation technologies call for continuous control to be exercised over basic radiation parameters. In principle, it is achievable using either transparent transducers of the MIT-type, or radiation flux weakly perturbing transducer. The latter implies low energy losses by a particle during its interaction with the transducer. Preferable, as well, are measurement instruments allowing to use one transducer to obtain date on various radiation parameters. This approach has been implemented by us while developing radiation measurement sets for different applied technologies.

2.1 Electron radiation monitoring

For continuous non-perturbing control of the high-power (≥10kW) scanned electron beam main parameters, “Accelerator” R&D Establishment has developed a measurement channel, employing a phenomenon acoustic signal excitation in a thin magnetostrictive line. The primary transducer is a **FeCo 50%** tape, 0.3 mm wide and 50 μm thick, strung along the scanning line. Relying upon a special electric circuitry and a computer, this instrument provides a real-time control over such beam parameters as scanning area length, most probable electron energy value, transverse dimensions and energy spectrum width. Developed, as well, is a scheme of the instrument remote testing [4].

2.2 Bremsstrahlung monitoring

A number of radiation technologies employ HP (≥1kW) bremsstahlung radiation fluxes with the transverse cross-section up to 500 mm and more, obtainable, as a rule, by way conversion of HP scanned electron beams. For control over such radiation, “Accelerator” Establishment has developed and constructed a measurement channel in which the primary transducer is a wide aperture ionization chamber. It allows to take real-time energy flux measurements.

CONCLUSIONS

Described in this report, the reference measurement complex is used for metrological support of scientific and applied radiation physics programs and custom technological processing, performed by NSC-KIPT “Accelerator” R&D Establishment. A member of measurement sets find their applications for certification of some radiation technology facilities of Russia and Ukraine, as well.

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