

CALIBRATION OF ELECTRON BEAM MEASURING CHANNELS IN TECHNOLOGICAL LINACS

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Abstract

Technologies based on electron (bremsstrahlung) irradiation demand continuous monitoring of the main beam parameters (energy, current, position etc.) and periodic calibration of the beam control system as well. Recently a number of technological electron linacs with an energy 10...30 MeV and pulse current up to 1A have been put in operation in National Science Center "KIPT" [1]. Each of them is provided with a system for scanning the output beam within the limits of 50 x 200 mm. The inductive wide-aperture non-disturbing sensor has been designed to control electron energy and beam position within the exit window of the accelerator. The monitor is provided with appropriate electronic set up. For its calibration relative to electron energy and beam current value the combined measuring transducer of "calorimeter-Faraday cup" type was elaborated. The report contains results of the computer modelling, design and investigation of transducers as well as their application in control systems of accelerators.

INTRODUCTION

The technological object irradiation zone is formed by the magnetic scanning system [2] provided by the laminated electromagnet with spatially homogenous field and normal boundaries on the beam input and output. The magnet is fed by the generator of the two-polar saw-tooth current. The scanning system provides the required size and uniformity of the irradiation zone as well as the measurement and operative control of the accelerated electron's energy.

The electron beam is injected to the atmosphere through a thin titanium foil. The swing of the beam track in the foil is executed within a length up to 12 cm. The basic characteristics of the accelerator beam and scanning device are presented in the Table 1.

1 BEAM SCANNING & MONITORING

The uniformity and size of the irradiation zone are determined by beam parameters, the quality of the magnetic field of the scanning magnet, the time characteristics, and the form of the magnet feeding current. Fig.1 shows schematically the scanning zone geometry from the accelerating section outlet to the exit window with real boundaries of the edge field on the inlet and outlet of the magnet clearance.

Table 1: Parameter specifications

Parameter	Value
The electron energy	$\bar{A}=8-25$ MeV
The beam diameter at the inlet of the scanning device	$\varnothing \approx 1$ cm $(r_0 = z_0 = \pm 0.5$ cm)
The input beam angular divergence	$r'_0 = z'_0 \approx 5 \cdot 10^{-3}$ radn
Energy dispersion	$\Delta E / E \approx \pm 5 \cdot 10^{-2}$
The maximum angle of the beam scanning	$\varphi = \pm 20^\circ$
The effective length of the magnet field	$L_n \approx 16.3$ cm
The scanning frequency (controlled)	$f = 1 \dots 3$ Hz

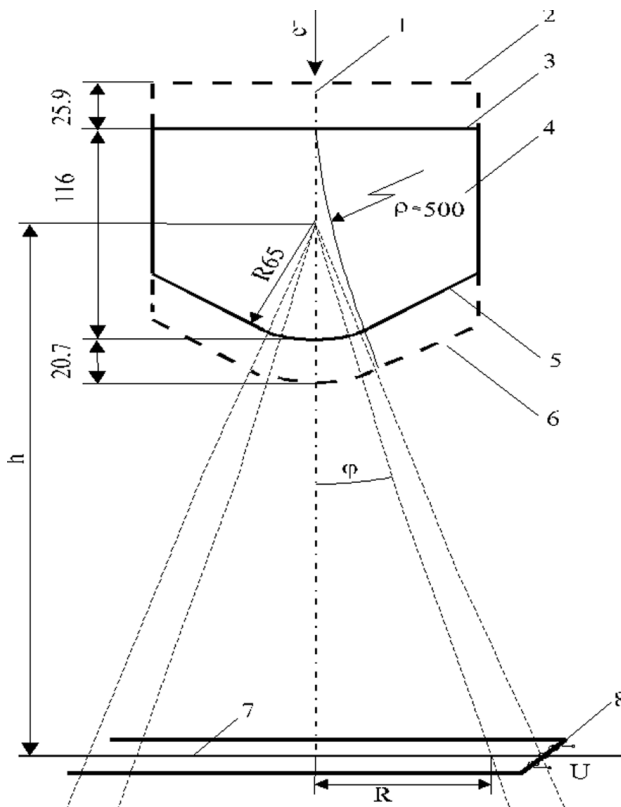


Fig. 1. The zone of beam scanning and output: 1- the accelerator axis; 2 and 6- the effective field boundaries on the inlet and outlet of the scanning magnet; 3 and 5 - the magnet boundaries (by iron); 7- the beam energy and location control plane; 8- scanning beam position monitor (SBPM).

The magnetoinductive scanning beam position monitor is placed in the atmosphere at 40 mm from the exit window foil (Fig.2). The monitor aperture is 50 x 200 mm, the ferrite core cross-section is 10 x 20, mm. The

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number of winding coils is 30. Amplitude of the signal U generated in the winding by the pulse electron beam I_p is proportional to the I_p value and inversely proportional to the distance Y to the winding:

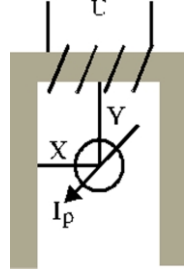


Fig.2 The SBPM scheme

$$Y = aU / I_p + b \quad (1)$$

where the coefficients a, b were determined during the bench test when a rectangular current pulse of duration 4 μ s was advanced along a thin conductor. Obtained dependence in the current amplitude real range ($I_p = 0.7$ A) is presented in Fig.3. The slope of the monitor characteristic (Fig.3,a) is 3.4 mV/mm.

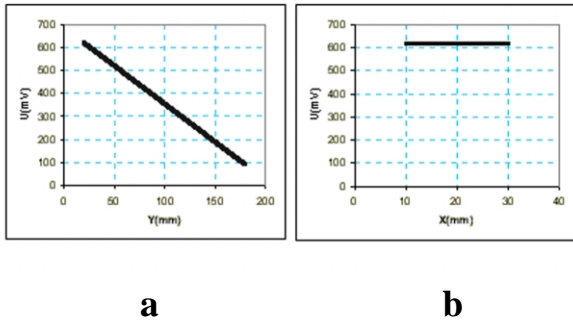


Fig.3. Amplitude U versus coordinate Y (a) and coordinate X (b)

2 OPERATIVE CONTROL METHOD OF THE ELECTRON ENERGY

It was shown [3] that the electromagnet M of the output device can be used for the operative control of the electron energy. The proposed technique is based on the relationship between the total energy of the charged particle E_k and the magnetic field factor $H\rho$:

$$H\rho = \frac{1}{ec} \sqrt{E_n^2 - E_0^2}, \quad (2)$$

where c - is the light speed, e and $E_0 = 0.5$ MeV- are the electron charge and rest energy, respectively, ρ - is the radius of the particle trajectory in the magnetic field with intensity H . The following expression for the kinetic energy of the electron E_k can be obtained by a simple transformation of (1) taking into account dimensions and units of measurement:

$$E_k = \sqrt{E_0^2 + (3 \cdot 10^{-4} H\rho)^2} - E_0, \quad (3)$$

where E_k is determined in MeV, ρ in cm.

One can see that to measure the E_k value it is enough to determine two values: the intensity of the deflecting magnetic field H and the radius of the electron orbit in this field ρ . However, while working with an accelerated beam, the direct measurement of the specified characteristics, especially ρ , is very difficult. That is why the technique is based on the measurement of the linear and angular parameters - the effective length of the deflecting magnetic field L_n (taking into account the scattered fields on the inlet and outlet of the magnet), and the geometry of the scanning zone (Fig. 1). These parameters are measured in advance and do not change their values during the experiment. The feeding current of the scanning electromagnet is obtained from the curve of magnetization $H = f(I)$. Noticing that for the small angles of the beam deflection ($\varphi \leq 20^\circ$) the following relationship is valid:

$$\rho = \frac{L_n}{\sin \varphi}, \quad (4)$$

we arrive at the practical formula for E_k :

$$E_k = \sqrt{E_0^2 + \frac{k^2 I^2}{\sin^2 \varphi}} - E_0, \quad (5)$$

where k is the constant accounting for the relationship between H , I and L_n for a specific magnet and is determined by bench testing. From Fig. 1 one can see that if the value of the electron beam deflection from the axis (R) on the plane located at distance h from the magnet is found by using any appropriate method and the value I is known, the most expectable value of E_k can be obtained. In this case:

$$\sin^2 \varphi = \left(1 + \frac{h^2}{R^2}\right)^{-1}. \quad (6)$$

$$R = Y - Y_0, \quad (7)$$

where Y_0 is coordinate of the direct (unscanned) beam.

3 CALIBRATION OF THE ELECTRON ENERGY MONITORING CHANNEL

3.1. The measuring channel based on the integrated sensor of "calorimeter-Faraday cup" type (ICFC-2) was designed for calibration of the monitoring system mentioned above relative to electron energy. The ICFC-2 sensor is a vacuum pumped Faraday cup with an optimized content and geometry of the sensing volume. This is used to decrease the leakage of the absorbed beam charge and energy by the secondary emission out of the active volume in the electron energy range 5...50 MeV. The study and optimization of the ICFC-2 metrological characteristics were performed via computer simulation of electron flux interaction with the sensor using the GEANT code elaborated in CERN [4,5]. The measuring scheme of the ICFC-2 consists of two tracts - absorbed beam charge

Q and beam energy W .

3.2. The ICFC-2 was placed at the exit window of LU-20 linac just behind the SBPM for direct calibration of the latter (Fig.4). The linac was operated with standard RF power regime without beam scanning at a pulse repetition rate was 150/16 Hz. In that way the dependence of the electron's energy middle value \bar{E}_k from beam pulse amplitude I_p was measured using the magnetoinductive probe RC as well. The latter has been calibrated also using the ICFC-2. So, the error of the beam current measuring by RC sensor is not more than 2%.

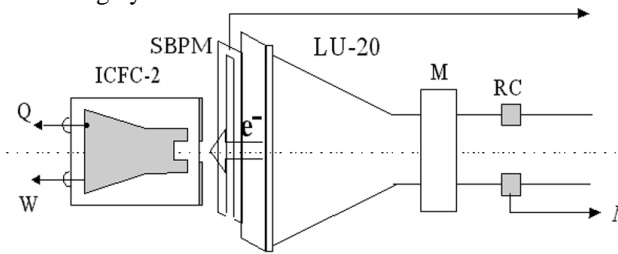


Fig.4. Beam calibration scheme

Later, the ICFC-2 was removed and the operation of the accelerator in the scanning regime was renewed. Thus the dependence of beam position R from electron energy \bar{E}_k was measured using the SBPM monitor. The obtained data are presented in the Table2. These results were used for SBPM calibration in energy terms.

Table 2

I_p , mA	\bar{E}_k , MeV	R , cm
330	40.7	4.4
425	32.4	4.8
630	30.7	5.9
770	26.9	6.7
810	24.1	7.4

3.3. A special system has also been developed [6] for control the electron beam current, energy and position. One of the system modules provides the simultaneous measurement of the values of the signals from the SBPM winding of the scanned electron beam location probe and the scanning magnet feeding current (Fig.5). By the results of the measurements of several scanning cycles maximum Y_{max} and minimum Y_{min} values of the electron beam center deviation are calculated and the value $2R = Y_{max} - Y_{min}$ is determined.

SUMMARY

The measuring channel described above enables the evaluation of the current beam coordinate Y with an error of about 3%. The amplitude of the electromagnet current I_M is determined at the same time, and then the value E_k is calculated with an error of about 5%. The videogram of the process of the electron beam energy control is shown in Fig.6.

The measuring procedure for Y and E_k evaluation is performed without any disturbance of the accelerator operation and takes about 2 s.

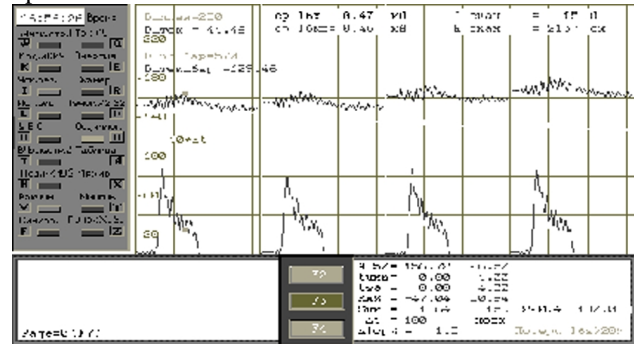


Fig.5. Videogram of the process of the electron beam position control

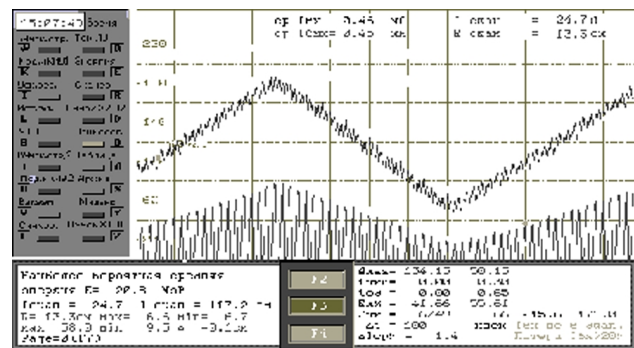


Fig.6. Videogram of the process of the electron beam energy control.

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