THE METHOD FOR ANALYSIS AND OPTIMIZATION OF THE e, X-BEAM PATH OF ELECTRON LINAC-BASED RADIATION INSTALLATIONS

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A method is proposed for numerical analysis of radiation characteristics of output devices of the electron linac. The method enables an optimum arrangement of the objects irradiated in the field of electron radiation and bremsstrahlung. Results are reported from the analysis of equipment location at the exit of one of the NSC KIPT electron linacs. The results were obtained by the mathematical simulation method with the use of the PENELOPE code system.

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1. INTRODUCTION

In modern radiation installations based on high-current electron accelerators a high-power bremsstrahlung is generated in the interaction of the beam with output device components. In addition to electron radiation, the bremsstrahlung may be used for carrying out technological programs (e,X-beam devices). Here we propose the method for analysis and optimization of such devices.

The accelerator beam track, starting from the electron source, can be considered as a single multicomponent target consisting of the layers of different materials that are transverse with respect to the beam. The thickness of each layer is measured in the units of the average entire range of the electron in the given material at electron energy equal to the average energy of electrons from the source. We shall call thus obtained length of the electron accelerator as the stopping length. Using the method of simulation based on the PENELOPE code system [1], we calculate the characteristics of the radiation field as functions of the stopping path of the device for actual or anticipated variant of output equipment location there. The main characteristics among them are the energy yields of electrons, photons and their ratio. The analysis of the behavior of these characteristics, and also, of their variations in relation to the variations in the parameters of the equipment provides an optimum variant of the arrangement of targets for their irradiation with electrons and photons.

To illustrate the method, the quality of the particle beam path of the NSC KIPT accelerator LU-20 was analyzed. The accelerator has two targets, one of which being irradiated with electrons, and the other - with photons. Thus, the given accelerator is a realized variant of the e,X-device.

2. THE MAIN STATES OF e,X-RADIATION AFTER PASSING THROUGH TARGETS OF DIFFERENT THICKNESSES

Let the monochromatic electron beam of energy E_0 be incident on the target of arbitrary material of given thickness. The target thickness measured in the units of the average entire electron range in the target material will be called as the stopping thickness.

The summed energy of electrons incident on the target is denoted as E_{beam}. Electrons with the summed energy E_{el} and photons with the summed energy E_{ga} are emitted from the target in the direction of the incident beam. Positrons emitted from the target are neglected. The E_{el}/E_{beam} ratio is the electron transmission coefficient, the E_{ga}/E_{beam} ratio is the energy coefficient of electron-to-photon conversion, the E_{ga}/E_{el} ratio is the photon beam quality factor, which characterizes the degree of electron content in the beam.

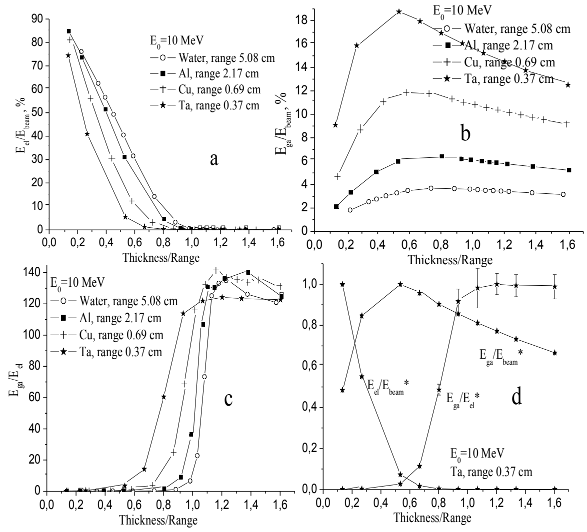

Fig.1. The coefficients of transmission (a), conversion (b), photon beam quality (c), and also, normalized coefficients for tantalum (d) as functions of the stopping target thickness, E_0 = 10 MeV

Fig.1 shows the calculated above-mentioned characteristics of radiation as functions of the stopping thickness of targets made of different materials in a wide range of atomic numbers for E_0 = 10 MeV. As it is obvious, for all the materials under study, the characteristics show a qualitatively similar behavior. This is shown in Fig.1,d, which gives the characteristics for tantalum, each being normalized for its maximum value.

It can be seen from the example with tantalum that as the target thickness increases; the state of radiation at the target output goes through three main stages.

At the first stage, at a target thickness ranging from zero to 0.5 there occur the deceleration and stopping of beam electrons, accompanied by a rise in the bremsstrahlung intensity up to the maximum value.

At the second stage, at thicknesses between 0.5 and 1.15, there occurs the formation of a dynamically equilibrium secondary radiation, with photons being its main component. At this stage, an intense improvement in the photon beam quality up to the maximum value takes place.

At the third stage, at thicknesses between 1.15 and more, the absorption of the formed secondary radiation occurs. The process goes in such a way that the E_{ga}/E_{el} ratio stays high and decreases very slowly as compared with the drop in the photon intensity (photon-electron equilibrium [2]).

3. ANALYSIS OF THE BEAM PATH IN THE INSTALLATION WITH THE ACCELERATOR LU-20 AS THE BASIS

The scheme of output devices in the accelerator beam is presented in Fig.2. Along the beam, there go in succession: the exit window foil (Ti, 50 μ), then in the air – the scatterer plate (Al, 2 mm), the vessel (Al, the front wall is 1 mm thick, the rear wall is 5 mm thick) with target 1 (2.67 g/cm^3 density, measures 40×40× 2.5 cm), the converter device from a 1 mm tantalum plate, and the 8 mm aluminum plate assembly unit. Behind the converter, there is the target 2 (3.36 g/cv^3 density, same size). The distance from the foil to the second target is 164 cm.

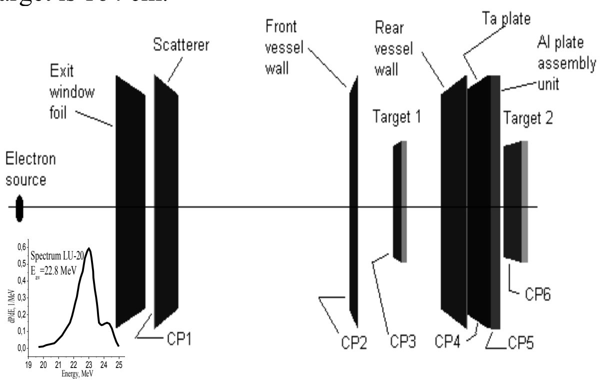

Fig.2. Scheme of peripheral units of the accelerator LU-20

The electron beam energy spectrum is shown in the inset of Fig. 2. The average electron energy value makes 22.8 MeV. At this energy, computations were made to obtain the entire ranges of electrons in Ti, air, Ta, Al, target 1, target 2, and also the stopping thicknesses of the corresponding output devices and air gaps. The sum of thicknesses of all the components makes the stopping length of the output device of the accelerator.

The radiation field characteristics were determined in the front planes of the components (control points, see Fig.2): CP1 is a front plane of the Al scatterer, CP2 is the 1st wall plane of the target 1 container, CP3 is the 1st wall plane of target 1, CP4 is the 1st wall plane of the Ta plate of the converter, CP5 is the 1st wall plane of the Al unit of converter plates, CP6 is the 1st wall plane of target 2. The mentioned control point numbers CP1, CP2 (or 1, 2), etc., are shown in Fig.3.

Figs.3,a1, b1, c1 give radiation field characteristics of the operational e,X-device based on the LU-20, and Figs.3,a2, b2, c2 illustrate the variations in these characteristics with an increase in the tantalum plate thickness up to 7 mm. With a growing plate thickness points 5 and 6 get shifted. Figs.3,a2, b2, c2 show new positions of point 5 and the associated corresponding new positions of point 6.

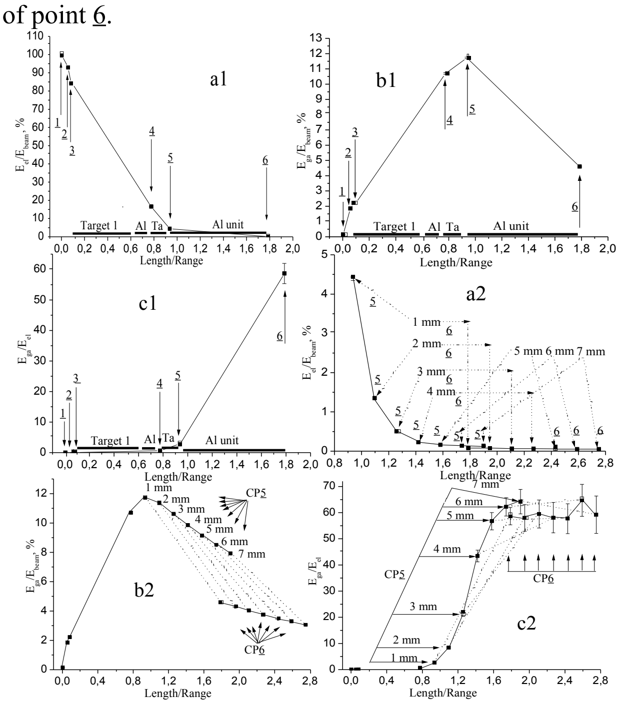

Fig.3. Coefficients of transmission (a1), conversion (b1), photon beam quality (c1) and variations of these coefficients (a2, b2, c2) (for different Ta plate thicknesses) versus stopping length of the output device

The data presented in Fig.3 show that target 1 is the main "consumer" of the electron beam. At the same time, together with the second wall of the container (denoted as A1 in the figure) and the tantalum plate target 1 serves as an e,X-converter, because at point 5 the conversion coefficient attains its maximum. Target 2, in its turn, is the "consumer" of the high-quality photon beam, because at point 6 the quality factor reaches maximum.

So, at accelerator LU-20 conditions, targets 1 and 2 are arranged in the optimum way.

Note that the LU-20 photon beam quality is increased by the aluminum plate assembly unit by a factor of 21.7 (Fig.3,c1). In this case, the conversion coefficient value falls from 11.7% down to 4.6% (Fig.3,b1). Thus, the aluminum unit plays the role of the electron filter. If this role is assigned to the 7 mm thick tantalum plate, and the aluminum unit is removed, then the beam quality will remain the same (Fig.3,c2), and the conversion coefficient will fall down to 7.9% (cf. 4.6% in Fig.3,b2). In this case, the photon yield is 1.7 times higher. At an unchanged quality, this means that the electron portion in the photon beam will be by the same factor greater. Therefore, light aluminum in the quality of a “cleaner” appears to be better than tantalum.

4. CONCLUSION

The proposed method for optimizing the arrangement of equipment and targets at the accelerator exit is one-dimensional, because only the energies of electron/photon components of the radiation are analyzed. The complete analysis must be three-dimensional, i.e., it must take into additional consideration the angular and radial divergences (emittance) of the beams, and also the dimensions of output device elements, which are transverse in relation to the beam.

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REFERENCES

1. F. Salvat, J.M. Fernandez-Varea, J. Sempau. *PENELOPE-A Code System for Monte Carlo Simulation of Electron and Positron Transport*. Workshop Proc. Issy-les-Moulineaux, France. 2003.
2. V. Veksler, L. Groshev, B. Isaev. *Ionization Methods for Radiation Research.* M.: “Gosizdat tekn.-teor. Lit. Publication”. 1949, p.51 (in Russian).

МЕТОД АНАЛИЗА И ОПТИМИЗАЦИИ e,X-ТРАКТА РАДИАЦИОННЫХ УСТАНОВОК С ЛИНЕЙНЫМИ УСКОРИТЕЛЯМИ ЭЛЕКТРОНОВ

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Предложен метод численного анализа радиационных характеристик выходных устройств ускорителя электронов. Метод позволяет оптимально расположить объекты, облучаемые в поле электронного и тормозного излучения. Приводятся результаты анализа размещения оборудования на выходе одного из линейных ускорителей ННЦ ХФТИ. Результаты получены методом математического моделирования с помощью программной системы PENELOPE.

МЕТОД АНАЛІЗУ ТА ОПТИМІЗАЦІЇ e,X-ТРАКТА РАДІАЦІЙНИХ УСТАНОВОК З ЛІНІЙНИМИ ПРИСКОРЮВАЧАМИ ЕЛЕКТРОНІВ

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Пропонується метод чисельного аналізу радіаційних характеристик вихідних пристроїв прискорювача електронів. Метод дозволяє оптимально розмістити об’єкти, що опромінюються в полі електронного і гальмівного випромінювань. Приводяться результати аналізу розміщення устаткування на виході одного з лінійних прискорювачів ННЦ ХФТІ. Результати одержані методом математичного моделювання за допомогою програмної системи PENELOPE.