ELECTRON LINAC BASED e,X-RADIATION FACILITY*

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Abstract

In a number of technologies based on high-current electron accelerators bremsstrahlung is generated in the interaction of the beam with the irradiated object. Thus, in addition to the electron radiation, the bremsstahlung may be used for carrying out of different technology programs (e,X-facility).

A method for the numerical analysis and optimization of the radiation characteristics of such installation is proposed. The accelerator beam track is considered as a single multicomponent target consisting of the layers of different materials. The thickness of each layer is measured in the generalized units of the "stopping length". Using the method of simulation based on the PENELOPE/2001 system the characteristics of the mixed e,γ-radiation field (energy yield of electrons, photons and their ratio) as function of the stopping length of the device for actual or anticipated version of output equipment can be calculated. To illustrate the method, the parameters of the beam path of the NSC KIPT Linac LU-20 used as e,X-facility were analyzed.

INTRODUCTION

In the design of the target device it is necessary to take into account the both components of the mixed e,X-radiation field. The variants chosen, as well as the material and the geometry will exert an effect on the formation of electron and bremsstrahlung fluxes, and, as a consequence, will determine the absorbed power in each output device element. Usually, these processes are investigated by the computer simulation method. This takes many efforts to develop the programs and much time for their realization. In this report we propose a simplified method of analysis of the radiation field in the output part of the electron accelerator.

The accelerator beam track, starting from the electron source, and up to output devices is 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 length. 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 version 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 [2]. 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-facility.

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 stopping length 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 mixed radiation.

Fig.1 shows the calculated above-mentioned characteristics of radiation as functions of the stopping thickness of targets made from 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.1d, 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

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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).

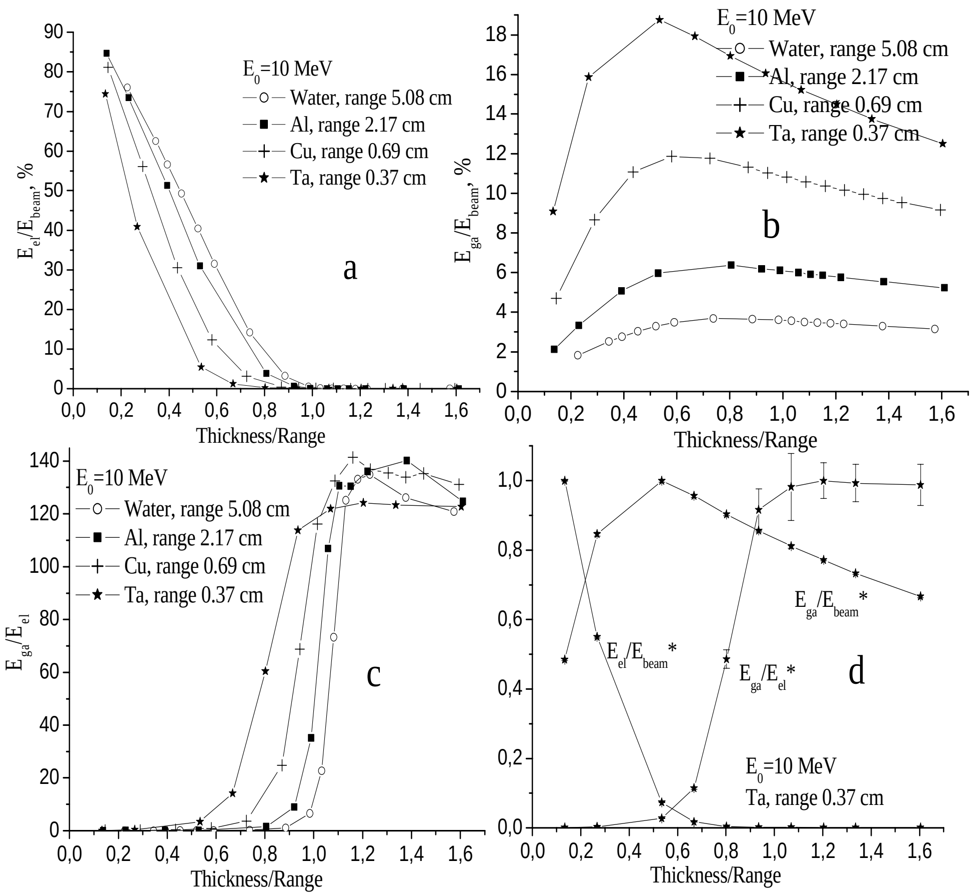

Figure 1: The coefficients of transmission (**a**), conversion (**b**), photon beam quality (**c**), and also, normalized coefficients for tantalum (**d**) as functions of the stopping target thickness

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.

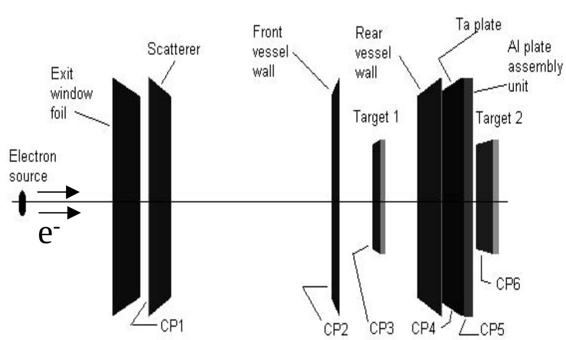

Figure 2: Scheme of peripheral units of the accelerator LU-20

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 40x40x2.5 cm^3), the converter device from a 1 mm tantalum plate, and the 8 mm aluminum plate assembly unit. Behind the converter, there is target 2 (3.36 g/cm^3 density, same size). The distance from the foil to the second target is 164 cm.

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 elements and air gaps. The sum of thicknesses of all the components makes the stopping thickness 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 – front plane of the Al scatterer, CP2 – 1st wall plane of the target 1 container, CP3 – 1st wall plane of target 1, CP4 – 1st wall plane of the Ta plate of the converter, CP5 –1st wall plane of the Al unit of converter plates, CP6 - 1st wall plane of target 2. The parameters of radiation at the mentioned control point numbers CP1, CP2 (or 1, 2), etc., are shown in Fig. 3.

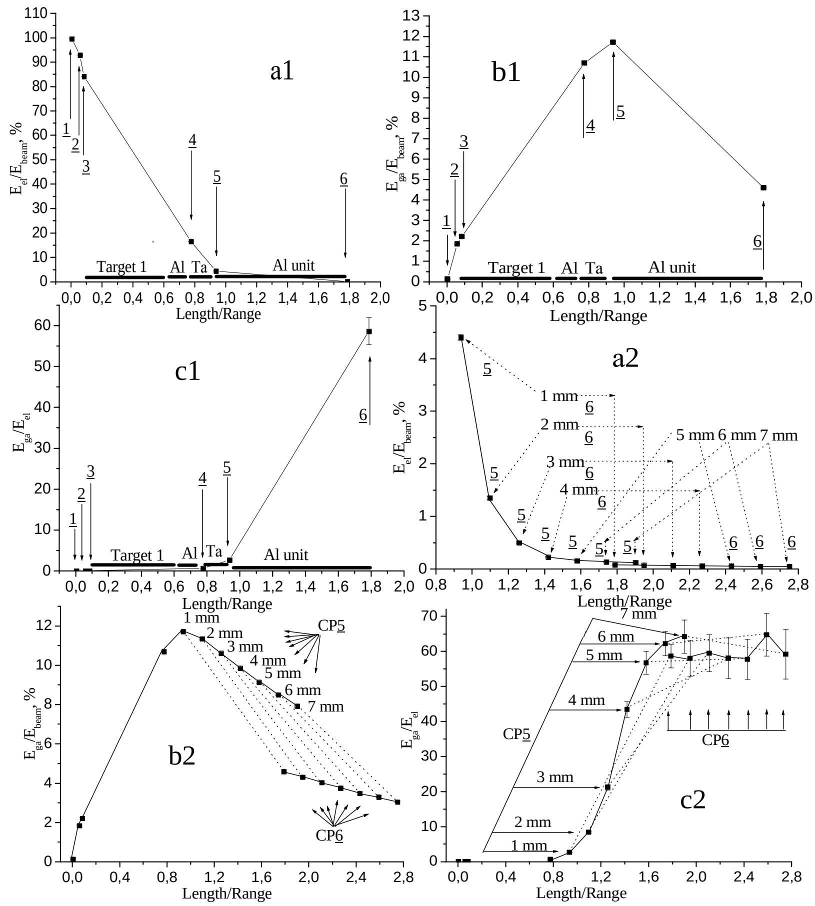

Figure 3: Coefficients of transmission (a1), conversion (b1), photon beam quality (c1) and variations of these coefficients (a2, b2, c2) (for different Ta plate thicknesses) versus stopping thickness of the output device.

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. Figures 3(a2,b2,c2) show new positions of point 5 and the associated corresponding new positions of point 6.

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.

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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