IMPROVING OF UNIFORMITY OF THE ELECTRON-BEAM TREATMENT OF MATERIALS BY ELV ACCELERATORS

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Abstract

The problem of the absorbed dose distribution during the EB treatment by ELV accelerator is considered. The value of the absorbed dose is determined by the speed of scanning electron beam along the accelerator exit window (i.e. the movement across the conveyor). It is determined both by the shape of scanning current and by the geometry of scanning magnets. A simple way to improve the dose distribution near the edges of the extraction device of accelerator is suggested. It allows to provide the non-uniformity less 4%.

INTRODUCTION

ELV accelerators produced by the Budker Institute of Nuclear Physics (Novosibirsk), has the leading position among the proposed equipment for radiation processing of materials. High performance, wide range, covering almost all the needs of modern industrial technology, reliability and relative ease of use and maintenance form the strong demand for this product in tough market conditions. The technology development radiation modification increases the requirements for the parameters of industrial accelerators produced by stimulating the creation of more powerful and energy efficient models [1]. In a number of industrial applications emerge and increased demands on other characteristics ELV accelerators, such as the stability of the energy of the beam current, the uniformity of the irradiation and etc. The condition of uniform dose distribution to be no more than 4% of the length of the material is an example of such a requirement. It occurs when you use the extended length of the output window, as in the modernization of the accelerator, which took place in spring 2012.

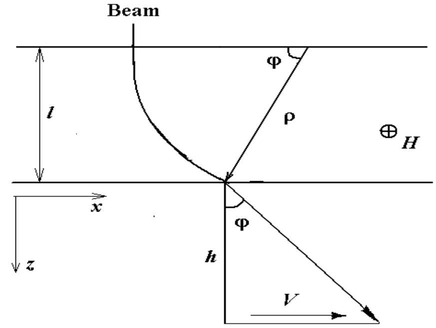
THEORETICAL PART

The dose of radiation is determined by the current density and linear scanning speed of the beam along the axis of the output device. In Figure 1 shows the trajectory of the electron beam in the deflecting magnets in the form of unlimited axis x band width l (the using of cylindrical poles, that takes into account the effect of the edge focusing, is shown in Figure 2) and the calculated reduced velocity (V) of a beam and reduced radiation dose (D ~ 1 / V) as a function of deflecting magnets current. These formulas are obtained by taking into account that

$$\sin(\varphi) = \int_l Hdl \Big/ (H\rho)$$

where $H\rho$ – given the relativistic momentum of the electron, and the integral can be written as

$$\int_l Hdl = K \cdot I(t), K = Const.$$



$$Y_V = \frac{V(\varphi)}{V(\varphi=0)} = \frac{1}{\cos^3(\varphi)}; Y_D = \cos^2(\varphi)$$

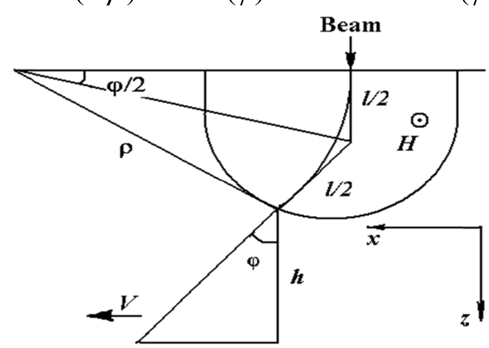
Figure 1: Forms of the scanner current in case of the unlimited axis x magnetic field band.

Thus obtain the following formula for the rate and dose

$$V = h\cdot\frac{K}{(H\rho)}\cdot\frac{1}{\cos^3(\varphi)}\cdot\frac{dI}{dt}; D \sim \frac{1}{V}\cdot\frac{1}{\cos(\varphi)} = \cos^2(\varphi)$$

and similarly for Figure 2 –

$$V = h\cdot\frac{K}{(H\rho)}\cdot\frac{\cos^2(\varphi/2)}{\cos^2(\varphi)}\cdot\frac{dI}{dt}; D \sim \frac{\cos(\varphi)}{\cos^2(\varphi/2)}$$



$$Y_V = \frac{V(\varphi)}{V(\varphi=0)} = \frac{\cos^2(\varphi/2)}{\cos^2(\varphi)}; Y_D = \frac{\cos(\varphi)}{\cos^2(\varphi/2)}$$

Figure 2: The trajectory of the electron beam and the horizontal velocity and dose formula.

In Figure 3 shows graphs of the calculated dose distribution and the actual measurements made by different energies. Differences are due to the scattering of the electron beam as the output device in the foil, and in the air. Contribute to the actual shape also makes scanning electromagnets, which real view (Figure 4) differs from the above described cases and have the form closer to Figure 1.

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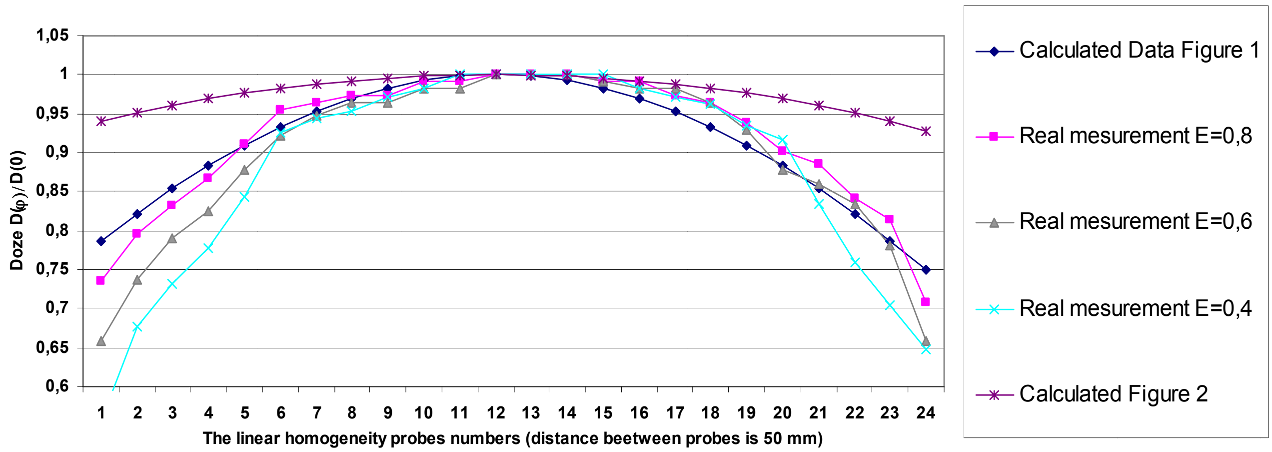

Figure 3: Comparison of calculations and actual measurements of the linear dose uniformity.

Figure 4. LF scanner coils.

The supply voltage is rectangular, and the functional dependence of the current on time can be represented as a series:

$$I(t)=\frac{4U_m}{\pi}\sum_{k=2n+1}\frac{\sin(wkt+\varphi_k)}{\sqrt{(kwL)^2+R^2}};\varphi_k=arctg\left(\frac{wkL}{R}\right)$$

where R - the total series resistance of the coil and wires, L - inductance coil scanner.

Current scanning system has a symmetrical sawtooth shape (Figure 4) due to the fact that the ratio of $wL/R \approx 35 >> 1$. With this form of current uneven dose in length 1800 mm exit window was ~ 10-12%. To increase the dose at the edges of the output device is necessary to reduce the rate of change of the current at the edges of the exit window. To do this, it was suggested to connect consistently with scanning coils capacitors. Form of the current in this case is defined as

$$I(t)=\frac{4U_m}{\pi}\cdot\sum_{k=2n+1}\frac{kw\sin(wkt+\varphi_k)}{\sqrt{(kwRC)^2+\eta^2}};$$

$$\varphi_k=-arctg\left(\frac{\eta}{kwRCR}\right);\eta=1-(kwLC),$$

where C - series capacitance is shown in Figure 5.

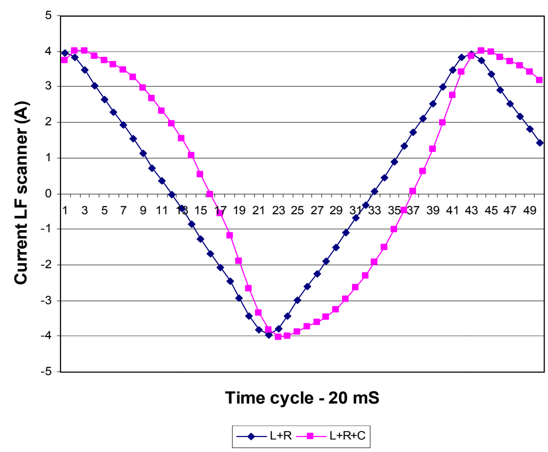

Figure 5. Forms of the scanner current.

The design capacity is in range from 240 to 300 μF.

EXPERIMENT

This technique was used to upgrade the accelerator to irradiate a wide polyethylene sheet in March 2012. When configuring in the real capacity was 250 uF. Measurement results of heterogeneity at different exposure settings, capacity and energy are shown in Figure 6. The result was achieved uneven doses of less than 4%.

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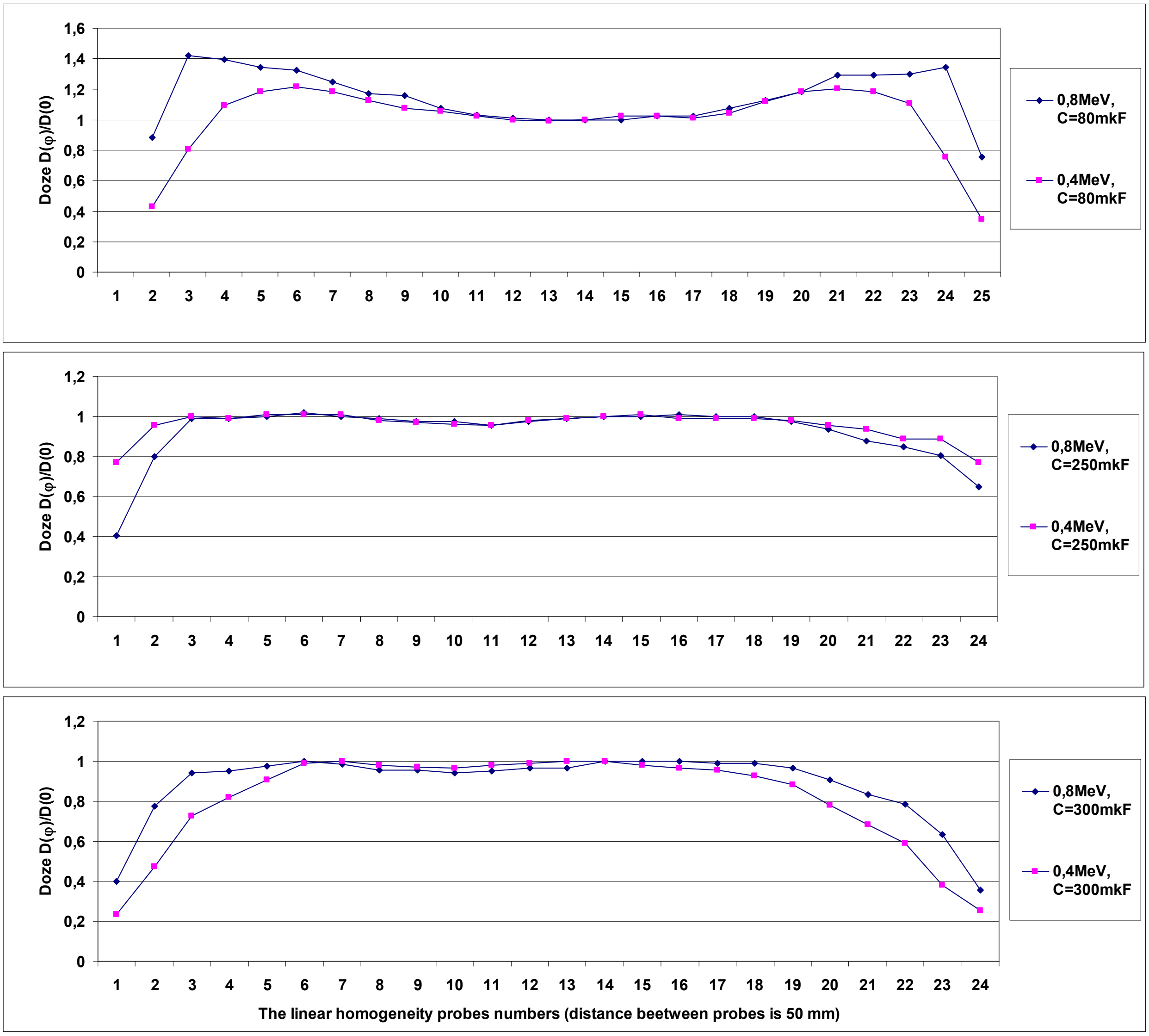

Figure 6: The dependencies of the radiation dose from the energy and capacity along the output window.

CONCLUSION

Proposed a simple method of increasing the dose at the edges of the output device of the accelerator (i.e. the reduction of inhomogeneous dose) will meet the manufacturing process by using existing hardware without a significant change of control systems by scanning the beam, which in the current small-scale manufacturing (it is now about 20 ELV accelerators produced each year and have been already successfully operated over 150 accelerator), unifies and simplifies the hardware support from the supplier.

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