ELECTRON BREMSSTRAHLUNG CHARACTERISTICS CALCULATION MODEL FOR A MULTI-LAYER CONVERSION TARGET PLACED IN A HYPERBOLIC MAGNETIC FIELD

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Abstract

The description of an electron bremsstrahlung characteristics calculation model for a multi-layer conversion target, placed in a hyperbolic magnetic field, is given. The bremsstrahlung characteristics from 10-layer copper target at electron energy up to 300 MeV were obtained. The thickness of each layer is equal to 0,05 radiation length. Quadrupole magnetic triplets are located between layers. It is shown, that the bremsstrahlung source intensity with use of suggested magnetic system grows almost in 1,8 times at registration cone equal to 1^{O}. For the numerical decision of equation of the charged particles movement in the magnetic field, given by a magnet, the linear difference method for a Koshi task approximation for first order ordinary differential equations system was used.

In our previous proceeding [1] the estimations of a bremsstrahlung flow limiting parameters, which can be achieved at use of a multi-layer target method [2], were made. It was supposed to create in an interval between target layers such magnetic field, which would cancel completely angular electron divergence, arising after their passage through the previous target layer. The present report is devoted to calculation of the electron bremsstrahlung characteristics from multi-layer conversion target placed in real magnetic field, instead of the idealized one.

In the report given for calculation of electron passage in a target material the same model as in [1] is used, and the calculation of an electron movement in an interval between targets is based on the movement equations in magnetic field approximated by hyperbolic functions.

The specific task calculation consists of two stages. At the first stage, depending on a kind of environment, the necessary crosssections and distributions are calculating. Then the results are used at the second stage for direct modeling of particles transfer.

For the numerical decision of the charged particles movement equation in the magnetic field given the linear difference method for a Koshi task approximation for first order ordinary differential equations system was used.

The basic equations for the task given, as it is known, look like:

$$\frac{du_i}{dt} + \sum_{j=1}^{N} a_{ij} u_j = f_i(t),$$
$$t \geq 0, \qquad (1)$$
$$u_i(0) = u_i^0, i = 1,2...N$$

Designating as $A = (a_{ij})$ a square matrix of the NxN size with elements a_{ij}, not depending on t, as $u(t) = (u_1(t), u_2(t)..., u_N(t))$ - required, and as $f(t) = (f_1(t), f_2(t)..., f_N(t))$ - given vectors of dimension N, we can write down system as

$$\frac{du}{dt} + Au = f(t),$$
$$t > 0, \qquad (2)$$
$$u(0) = u_0$$

Let's introduce a mesh with a step τ on variable t: $t_n=n*\tau$, $n=0, 1, 2...$ Also we shall designate as $y_n=y(t_n)$ mesh function of argument $t_n=n*\tau$. Let's write down the explicit method (Eiler method):

$$\frac{y_{n+1} - y_n}{\tau} + Ay_n = f_n \qquad (3)$$

$n=0, 1, 2...; y_0=u_0$

where $y_{n+1}=y_n-\tau(Ay_n-f_n)$, $n=0, 1, 2..., y_0=u_0$.

In general case the task (3) decision depends not only on t, but also on N or on parameter $h=1/N$. Not one task (3), and set of tasks for every possible t and h is actually considered. It is linear difference method.

Let's proceed to a specific task, namely, to the equation of the charged particle movement in a magnetic field. As the electrical field in this case is absent, this equation looks like:

$$\frac{d\vec{p}}{dt} = e\left[\vec{V}, \vec{B}\right] \qquad (4)$$

Where $\vec{p}$ - particle momentum vector, t - time, e - particle charge, $\vec{V}$ - particle velocity vector, $\vec{B}$ - a magnetic induction vector.

Let's expanse the equation (4) on coordinate axes

$$\frac{dp_x}{dt} = e(V_y B_z - V_z B_y)$$
$$\frac{dp_y}{dt} = -e(V_x B_z - V_z B_x) \quad (5)$$
$$\frac{dp_z}{dt} = e(V_x B_y - V_y B_x)$$

Let's replace in (5) p_i by mV_i (m – particle mass, electron in this case), and projections of velocity and acceleration vectors by appropriate coordinate time derivatives. We shall transfer also a particle mass to the right part. The result obtained is:

$$\ddot{x} = \frac{e}{m}(\dot{y}B_z - \dot{z}B_y)$$
$$\ddot{y} = -\frac{e}{m}(\dot{x}B_z - \dot{z}B_x) \quad (6)$$
$$\ddot{z} = \frac{e}{m}(\dot{x}B_y - \dot{y}B_x)$$

The system of the 2-st degree differential equation (6) describes charged particle movement in a magnetic field. For the decision of this system we shall pass on to system of the 1-st degree differential equations using variables replacement

$$\frac{dx}{dt} = u \quad \frac{dy}{dt} = v \quad \frac{dz}{dt} = w$$

The Koshy task for system of the ordinary 1-st degree differential equations and initial conditions in the elementary case is solved by Eiler linear difference method, considered above. For this purpose we shall replace continuous argument functions by mesh function.

$$\frac{df}{dt} \approx \frac{\Delta f}{\Delta t} = \frac{f_{i+1} - f_i}{\tau}, \; i=0,\, 1,\, 2... \quad (7)$$

Where i - a step number, τ - variable t step.

In a case of a quadruple lens (hyperbolic approximation) - $B_z=0$, $B_x=Gy$, $B_y=Gx$. The system of the equations will look so:

$$\begin{cases} x_{i+1} = x_i + u_i\tau \\ y_{i+1} = y_i + v_i\tau \\ z_{i+1} = z_i + w_i\tau \\ u_{i+1} = u_i - \dfrac{e}{m} w_i G x_i \tau \\ v_{i+1} = v_i + \dfrac{e}{m} w_i G y_i \tau \\ w_{i+1} = w_i + \dfrac{e}{m} G(u_i x_i - v_i y_i)\tau \end{cases} \quad (8)$$

Thus $x_0=x\ (0)$, $y_0=y\ (0)$, $z_0=z\ (0)$, $u_0=u\ (0)$, $v_0=v\ (0)$, $w_0=w\ (0)$.

The bremsstrahlung output analysis carried out for various electron energies, nuclear structure and targets thickness using formulas given has shown, that to obtain narrow-angle high-intensity bremsstrahlung flow it is necessary to use electrons with probably greater energy (we shall consider a range 30-300 MeV). Using some thin copper targets, it is possible to obtain bremsstrahlung output increase and reduction of its angular distribution width in comparison with one target of "optimum" thickness. However, an electron beam angular divergence is increased after passage of each target. It results in necessity to provide simultaneous effective electron beam focusing in both transverse directions. Hence, on each site between previous and subsequent targets it is necessary to use magnetic system, which could reduce electron beam angular divergence.

For the decision of problem put by, the system consisting of 3 magnetic quadruple lenses was used, because a magnetic doublet could not provide simultaneous reduce of beam angular divergence in both a transverse direction to sufficient value. The scheme of magnetic system is shown in a Figure 1.

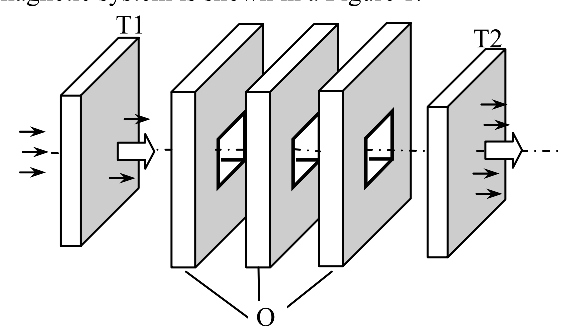

Figure 1: The scheme of magnetic system for a bremsstrahlung source with thin targets.

To select magnetic system parameters the program TRANSPORT, intended for calculation of charged particles beams transportation systems parameters, was used. This program uses matrix representation of magnetic system elements and allows to select parameters of system (magnets length, drift intervals length, magnetic fields gradients etc.) appropriate to the angular and linear beam sizes given on a system output.

Using the program of electrons dynamics calculation and the selected magnetic focusing system parameters, bremsstrahlung output dependences (part of falling electrons energy, transformed in bremsstrahlung) on falling electrons energy were obtained (Figure 2 - 4). The thickness of one target layer was equal to 0,05 rad. length.

The following designations were used in figures:

- E_0 - energy of electrons, MeV;
- E_{BR}/E_O - bremsstrahlung output, relative units;
- Trace 1 ($I\theta_0$) - bremsstrahlung intensity at absence of magnetic focusing system;
- Trace 2 ($I\theta_B$) - bremsstrahlung intensity at presence of magnetic focusing system;
- *Trace 3* ($I\theta_{id}$) - bremsstrahlung intensity at ideal focusing.
- θ - a registration cone.

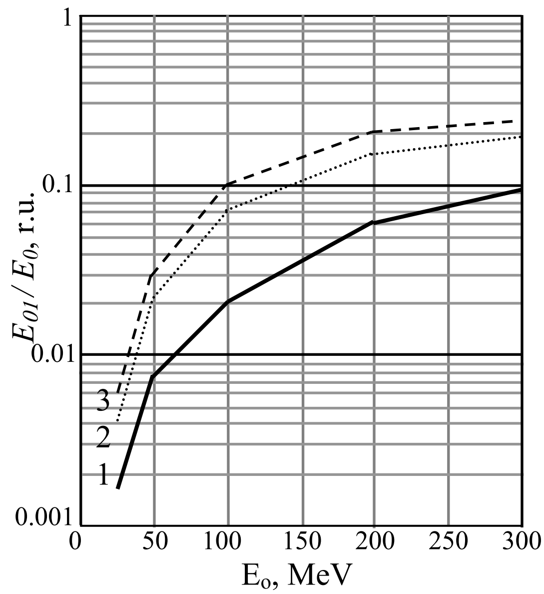

Figure 2: Bremsstrahlung output dependences on electron energy. Number of targets - 10. Registration cone $\theta = 1^{O}$.

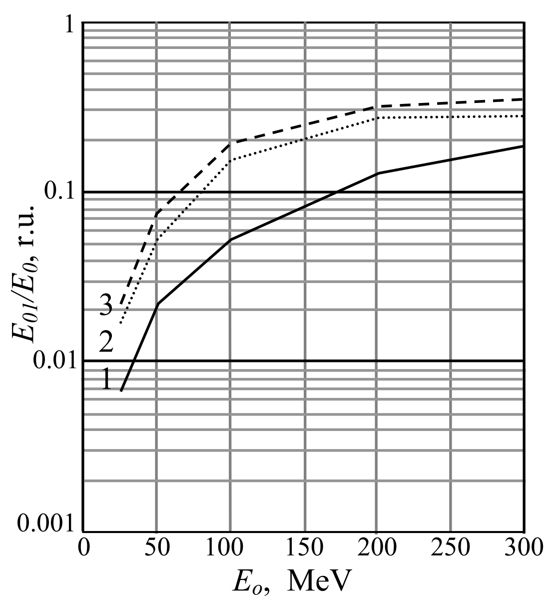

Figure 3: Bremsstrahlung output dependences on electron energy. Number of targets - 10. Registration cone θ=2^{O}.

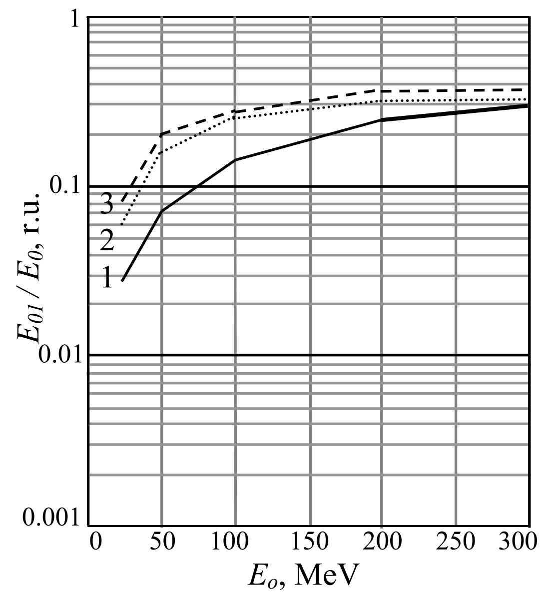

Figure 4: Bremsstrahlung output dependences on electron energy. Number of targets - 10. Registration cone $\theta = 5^{O}$.

Having analyzed the data obtained, it is possible to make a conclusion, that for the maximal bremsstrahlung output, the optimum number of targets in the considered example should be equal to 8-10, and an electron energy – about 100 MeV. Thus, the bremsstrahlung output within the registration cone equal 1^{0} will increase in 3,3-3,4 times in comparison to monotarget system whithout magnets.

REFERENCES

[1] Possibility of an electron bremsstrahlung output increase by use of a conversion target placed in a focusing magnetic field. P. V. Alferov, V. V. Kudinov, A. V. Nesterovich, V. V. Smirnov. Present at EPAC 2002, Paris.

[2] Formation of Bremsstrahlung Flow with Small Divergence at Linac Output for Planet Surface Sounding with Interplanetary Space Stations. Auth.: B. Bogdanovitch, V.Kudinov, S.Minaev, A.Nesterovitch, Yu. Pomazan. Proceedings of the 1999 Particle Accelerator Conference, New York, 1999, p.1291-1293.