BEAM DYNAMICS IN THE OUTPUT SYSTEM OF LINAC WITH SPECIAL TARGET FORMING BREMSSTRAHLUNG FLOW WITH SMALL DIVERGENCE

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Abstract

Beam dynamics in the output system of linac with special target forming bremsstrahlung flow with small divergence is described. The development of this method restrained by radiation large angular divergence, caused target significant thickness at the accelerator. Both dispersion electrons and dispersion photons occur on such thickness. The "wiggler" type system can be used for radiation divergence reduction. In this system the step repeating parallel displacement of the electron bunch is carried out by means of the sequence of bending magnets. Between pairs of magnets the thin targets (foils) are mounted, in each of them electron bunch radiates in a narrow cone angle. Foils are displaced from each other in such a manner that the bremsstrahlung flow do not pass through the subsequent foils. Thus the magnetic fields can have such distribution, that electrons fall onto each foil with the minimal angular disorder. The calculation show, that electron decelerating from energy (150-200) MeV to (50-100) MeV can be carried out at the distance smaller than several meters. In this case the induction does not exceed 2 T. Foil number is no more than 10. In this case the forward bremsstrahlung intensity is increased by the order. The installation with an induction up to 10 T and length about 1 m is also considered.

1 INTRODUCTION

The electromagnetic x-ray radiation (or bremsstrahlung) has found wide application in various areas of science and engineering. Electron linacs are usually used as a source of particles.

For increase of a bremsstrahlung output it is necessary to raise thickness of a target. However, a radiation divergence cone angle can reach tens of degrees, so intensity of bremsstrahlung is decreased. For a given target substance and electron energy, there is the optimum thickness of a target, with which the bremsstrahlung output reaches the maximum. However, when using a target with optimum thickness not all electron energy is absorbed in a target material.

In papers [1-2] the research results of various ways of electron flows radiation formation, driven on a cyclic or spiral orbit were considered. The opportunity of a radiation intensity increase due to electron multiple passage of the thin target under condition of the electron adiabatic cooling was experimentally confirmed. Those ways were restricted by the maximum energy and minimum radiation flow divergence caused by realising design specificity.

In paper [3], the research results of system intended for electron beams with energy up to several hundreds MeV and angular divergence (1-10) mrad were presented. In this paper, beam dynamics in such output system is described.

2 LAYOUT OF THE BREMSSTRAHLUNG FLOW FORMATION SYSTEM

A general layout of the bremsstrahlung formation system [3] is shown in Fig. 1.

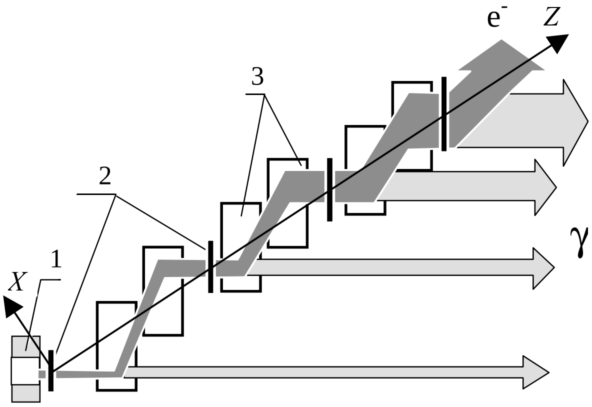

Figure 1: The bremsstrahlung flow formation (1 - electron accelerator; 2 - foils; 3 - magnets).

To avoid attenuation of X-ray radiation in a target and to increase efficiency of an electron beam usage, it is proposed to set a sequence of thin targets (foils) in periodic magnetic system (PMS) with a vertical bending magnetic field having alternative directions (the "wiggler" type system). In such system, the direction of the beam incidence on each foil can be made identical. Hence, directions of X-rays from each foil are near the same and, the attenuation effect in foils is diminished.

The beam angular disorder is increased by jump after each foil passing, and emittance of electron beam is increasing. The proposed PMS with thin foils can partially compensate the effect of beam divergence growth. With the successfully chosen PMS and foils, the electron beam can have smaller angular divergence, but more large cross sizes in comparison to a thick target.

The thickness of foils defines an angular divergence of radiation. It is obvious, that bremsstrahlung photons, produced in the target depth, also have a wider angular spectrum. Thus, if a subject of interest is the energy irradiated within a small cone angle, it is possible to tell, that the beam use efficiency on a thick target decreases not only due to attenuation in deep layers, but also because of the electron angular disorder increase. Thus, the proposed system can increase productivity of a beam for generation of radiation streams with low divergence.

3 NUMERIC SIMULATIONS

To explore opportunities PMS with foils, numerical simulations have been performed. The analysis of PMS includes three major tasks:

1) dynamics of electrons in a periodic magnet system;
2) calculation of a dispersion of electrons on foils;
3) integration of a total angular distribution of X-ray radiation on all targets.

Approaches to solve tasks 2 and 3 has been discussed elsewhere [3]. The first task is considered below.

3.1 Beam Dynamics Code

To simulate dynamics of electrons in PMS, the computer code written in MATHCAD has been developed. The code calculates trajectories of charged particles in a quasi-periodic 3D magnetic field. The trapezoidal approximation for the longitudinal z-distribution of the vertical *y*-component of magnetic field B_y is assumed. B_y has constant values inside of each magnet and varies linearly in between of magnets.

The coordinate transformations on a small *i*-th step Δz of numerical calculations are expressed by the following equations:

$$x_{i+1,p} = x_{i,p} + (\beta_{x,i,p}/\beta_{z,i,p})\Delta z \ ,$$

$$y_{i+1,p} = y_{i,p} + (\beta_{y,i,p}/\beta_{z,i,p})\Delta z \ ,$$

$$\beta_{x,i+1,p} = \beta_{x,i,p} - \frac{e(B_i + B_{i+1})(1 + G_i x_{i,p})\Delta z}{m_0 c \gamma_{i,p}} + \delta\beta_{x,i,p} \ ,$$

$$\beta_{y,i+1,p} = \beta_{y,i,p} - \frac{e(B_i + B_{i+1})(1 + G_i y_{i,p})\Delta z}{m_0 c \gamma_{i,p}} + \delta\beta_{y,i,p} \ ,$$

$$\beta_{z,i+1,p} = \sqrt{\beta_{x,i,p}^2 + \beta_{y,i,p}^2 + \beta_{z,i,p}^2 - \beta_{x,i+1,p}^2 - \beta_{y,i+1,p}^2} + \delta\beta_{z,i,p} \ ,$$

with $\gamma_{i,p} = \left(1 - \beta_{x,i,p}^2 - \beta_{y,i,p}^2 - \beta_{z,i,p}^2\right)^{-1/2}$,

where *x* and *y* are the transverse coordinates, *z* is the longitudinal coordinate as shown is Fig. 2. β_x, β_y, β_z are the relative particle velocities normalized by the speed of light *c*. The charge and rest mass of electron are denoted by *e* and m_0. B_i is the value of B_y at the beginning of the (*i*+1)-th interval. G_i is the gradient of magnetic field. $\delta\beta_{y,i,p}$, $\delta\beta_{x,i,p}$, $\delta\beta_{z,i,p}$ are random fluctuations of velocities when the *p*-th electron interacts with foils.

It is assumed that during the interaction with a foil any electron loss a given part of energy and its energy spread is negligible.

3.2 Calculation Results

Parameters of PMS had been presented in our previous paper [3]. Fig. 2 shows values of $\mathbf{B}_y$ and the trajectory of the reference particle along *z*-axis. Vertical double lines show the positions of foils.

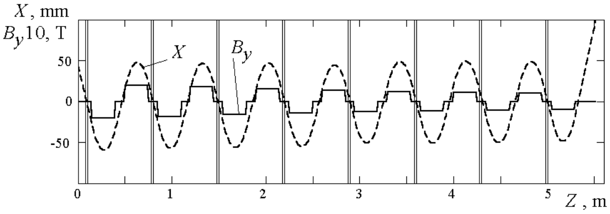

Figure 2: Trajectory of a reference particle and *z*-dependence of B_y.

To ensure a stable motion in a horizontal X0Z-plane, B_y has a constant gradient. Beam stability in the vertical Y0Z-plane is ensured by the well-known edge focusing. Figure 3 and 4 shows stable trajectories of some electrons in X0Z and Y0Z planes.

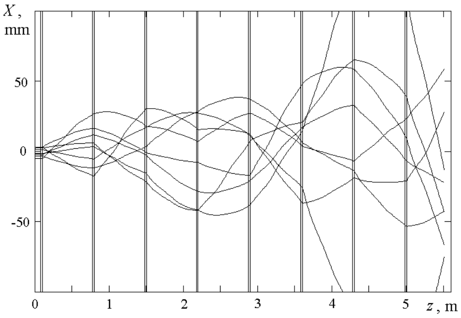

Figure 3: Electron trajectories in the X0Z-plane.

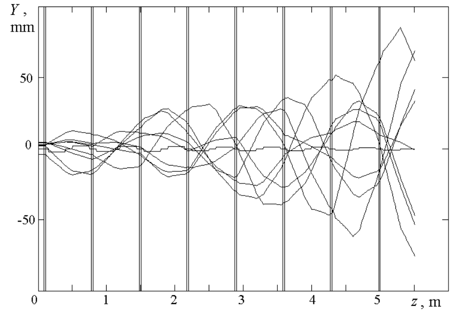

Figure 4: Electron trajectories in the Y0Z-plane.

Beam envelopes in both transverse planes are shown in Fig. 5. The envelopes are calculated for 90% of particles.

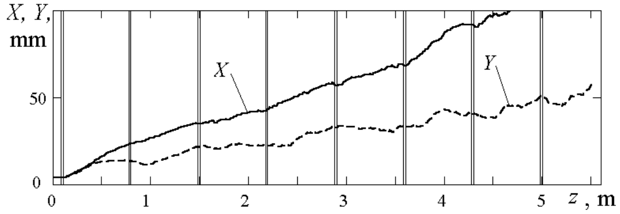

Figure 5: The beam envelopes.

Figure 6 present mean-root-values (or dispersion, D_x and D_y) of angle deviations, dx/dz and dy/dz. It is seen that the dispersions jumps up in foils and reduced in magnets. Focusing is smooth in X0Z-plane and spasmodic in the Y0Z-plane at the magnet edges. Values of envelope and dispersion grow up along the PMS system.

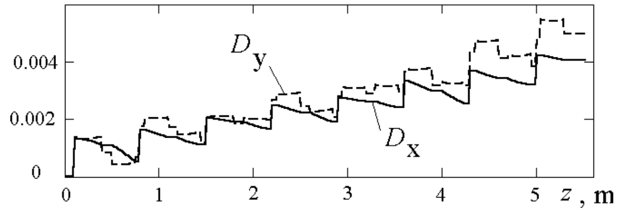

Figure 6: Mean-root-values of dx/dz and dy/dz.

The phase spaces of electron beam at the input and output of PMS system are shown in Figure 7. The 200-MeV input beam is simulated by 300 computer particles and corresponds to K-V distribution in transverse planes. Obviously, focusing by fields of PMS can not prevent an emittance growth. The emittance is increased in several orders of magnitude.

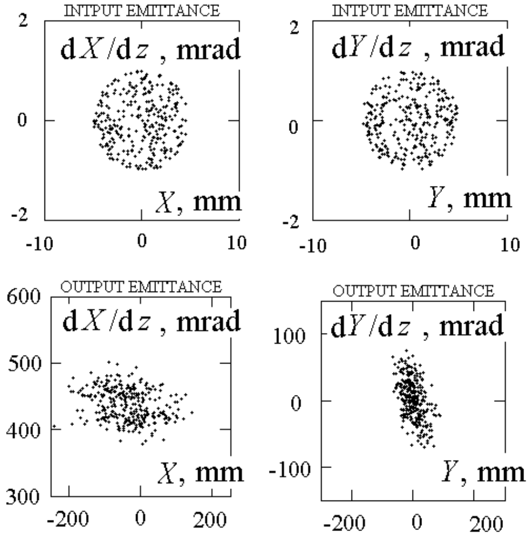

Figure 7: The phase spaces of electron beam at the input and output of the system.

Angular distribution of the radiation energy has been calculated according to the method described in paper [3]. In Figure 8 the radiation density from PMS with thin foils is compared with radiation from a thick target. In case of the proposed PMS with thin foils, the forward bremsstrahlung intensity is increased by the order.

Two cases of PMS have been considered. The first case is "warm" PMS with the induction less than 2 T. The second case is the superconductive PMS with the induction up to 10 T. The superconductive system with about 5 times greater induction allows to reduce overall dimensions of system by the 5 times. For 200-MeV electron beam number of foils is no more than 10 and overall dimensions are 5.5 m and 1.1 m for "warm" and superconductive PMS, respectively.

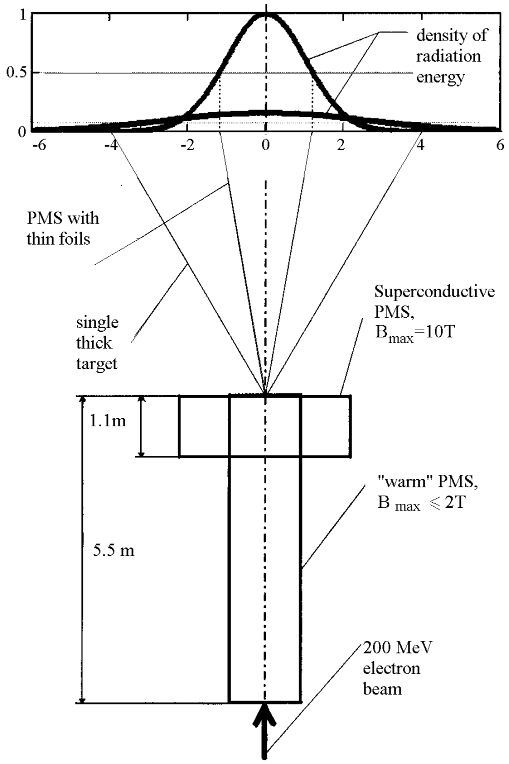

Figure 8: Angular distribution of the density of the radiation energy and overall dimensions of "warm" PMS and superconductive PMS.

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