MONOCHROMATIC HARD RADIATION SOURCE ON BASE OF 70-MEV RACE TRACK MICROTRON

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Abstract

Creation possibility of monochromatic hard γ-radiation source on base of the high quality accelerator like 70-MeV Race Track Microtron [1] is considered. Quality of accelerated beam permits to utilize it to elaborate a source of hard γ-photons. One of most effective mechanism for applying here is coherent bremsstrahlung (CBR) of electrons in a crystalline target. In particular using of diamond and silicon crystalline target allows to generate the polarized photons with energy up to 30-50 MeV. Estimations predict the CBR intensity in this photon energy region can at more than two times surpass over incoherent radiation one. To increase CBR photon yield, the possibility of special scheme use with multiple crossing of crystal target by electrons is analyzed. In the similar scheme the yield of monochromatic radiation can rise up an order.

1 INTRODUCTION

Using of hard monochromatic radiation can open wide field of different application. Modern electron accelerators like 70-MeV Race Track Microtron [1] with high quality of accelerated beams permit to do a new step in this relation. 70-MeV Race Track Microtron is designed to obtain 16 μs pulses of accelerated electrons with a current 0.1-40 mA, energy 10 - 70 MeV with a step of discrete change at 5 MeV, and small divergence at 0.2-0.3 mrad. Properties of accelerated beam permit to utilize it to elaborate an effective source of hard γ-photons.

One of most effective mechanism for applying here is coherent bremsstrahlung radiation (CBR) of electrons in a crystalline target. Versatile theoretical and experimental study of CBR properties (see for example the work [2] with first mention of CBR effect and ones of last works [3,4]) has shown that this mechanism allows to obtain a monochromatic polarized emission with photon energy to energy of radiant electrons.

However these results were received basically at rather high energies of radiating electrons above than hundreds MeV. The 70-MeV accelerator allows to use electron beams with more moderate energies in CBR researches. Possibilities of the traditional and circular schemes of CBR generation are examined below.

2 TRADITIONAL CBR SCHEME. PROBLEM OF OPTIMIZATION

CBR results from resonant amplification of particular frequencies in at a motion of relativistic electrons in a single crystal. In traditional scheme, relativistic electrons are dropped on a crystal target under a certain angle with respect to crystalline planes or axes. Intercrossing them, electrons experience periodic collisions with knots of a lattice. As the spectrum of a bremsstrahlung radiation extends up to frequencies at which one energy of quantum is comparable to energy of electrons, CBR mechanism allows to generate rather strong photons.

Resonant CBR conditions are determined by the following relations.

$$E_e = E_f + \hbar\omega \qquad (1a)$$

$$\vec{p}_e = \vec{p}_f + \hbar\vec{k} + s\hbar\vec{g} \qquad (1b)$$

where $E_{e,f}$ and $\vec{p}_{e,f}$ are values of energy and momentum of electron before and after emission of photon with frequency ω and wave vector $\vec{k}$, $\vec{g}$ is the vector of the reciprocal lattice, $s = 1,2,...$ Notice that the last term in the right part of the equation (1b) is describing the momentum transfer of electron to the crystal lattice.

Hence the photon energy radiated at small angle θ with respect to incident electron is

$$\hbar\omega = \frac{2\gamma_e^2 s\varepsilon_g}{2\gamma_e \dfrac{s\varepsilon_g}{\varepsilon_0} + 1 + \theta^2\gamma_e^2} \qquad (2)$$

where γ_e and ε_0 are the relativistic factor and the rest energy of electron, $\varepsilon_g = h(\vec{g}\cdot\vec{v})$, $\vec{v}$ *is* the electron velocity (so magnitude $s\varepsilon_g/v$ is the longitudinal momentum transfer to the lattice).

So CBR photon energies are defined by electron energy and their orientation with respect to a crystal lattice. Thus at the given orientation the basic peak is accompanied by a series of satellites, distance between which decreases for higher photon energies.

In a source with the maximal electron energy 70 MeV the coherent mechanism allows to receive photons with tunable energy up to several tens MeV.

Besides CBR, here an incoherent bremsstrahlung radiation is present. Therefore total spectrum consists of coherent peaks and pedestal of a incoherent flow. The intensity ratio of these components and peak widths are

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defined in many respects by optimization conditions of a source, for example by choice of a crystal kind and optimum thickness of a target.

At an estimation of last values it is necessary to take into account competing processes. First of all it concerns with multiple scattering of electrons which breaks a coherence condition.

Intrinsic width of coherent peaks is inversely proportional to number of the periods which passes a radiating particle. So

$$\frac{\Delta\omega_{coh}}{\omega} \cong \frac{1}{N} = \frac{D}{t} \qquad (3)$$

where N is the crystal knot number hit by electron, D is the distance between two knots hit consequently by electron. On the other hand, due to multiple scattering

$$\frac{\Delta\omega_{sc}}{\omega} \cong 2\gamma_e^2\Delta\theta_{sc}^2 \to \gamma_e^2 \frac{t}{L}\frac{E_s^2}{E_e^2} \qquad (4)$$

where t is the target thickness, L is the electron radiation length, E_s = 21 MeV, E_e is specified in MeV.

Combining relations (3) and (4) one can receive a estimate for optimized thickness of a target.

$$t_{opt} \cong \left(\frac{DL}{E_s^2}\right)^{1/2} \qquad (5)$$

Using the optimized thickness of a target t_{opt} one can obtain the minimum of a radiation peak width and an angle of coherent emission [5].

$$\frac{\Delta\omega_{opt}}{\omega} \cong \left(\frac{E_s^2 D}{L}\right)^{1/2} \qquad (6)$$

$$\Delta\theta_{rad} \approx \frac{1}{\gamma_e N^{1/2}{}_{opt}} \to \left(\frac{E_s^2 D}{L\gamma_e^4}\right)^{1/4} \qquad (7)$$

At use of an optimum target makes of diamond or silicon target thickness about 10-20 microns. For thicker targets the total intensity of radiation is increased only at simultaneous growth of width of peaks.

Following works [3-5], it is possible to conclude that the highest intensity CBR to be reached at use of diamond or silicon as target material. The value of intensity makes of the order 10^{-4} ph/e (in cone with polar angle $\Delta\theta_{rad}$., see (7)) at energy of electrons in 70 MeV at relative width of peaks of the order 10 % for phonon energy in some tens MeV. Notice that phonon beams can have a high polarization. The amplitude of peaks approximately twice exceeds incoherent background.

3 NEW CIRCUITAL CBR SCHEME

Nevertheless the efficiency of CBR remains rather low, especially at use of electrons with energy about ten MeV. Really, optimum length of CBR makes about 0.01 % from value of radiation length. On the average, radiation losses of energy (and other losses too) by electrons correspond here to marked level. Therefore rather tempting is an idea of multiple use of an electronic beam in generation of CBR. This idea was successfully analyzed in work [6] in application to X-ray radiation generation of relativistic electrons in crystalline target (in Bragg's configuration). It does not cause doubt that scheme offered in [6] can appear fruitful at CBR generation too.

The suggested experimental setup is presented in Fig.1.

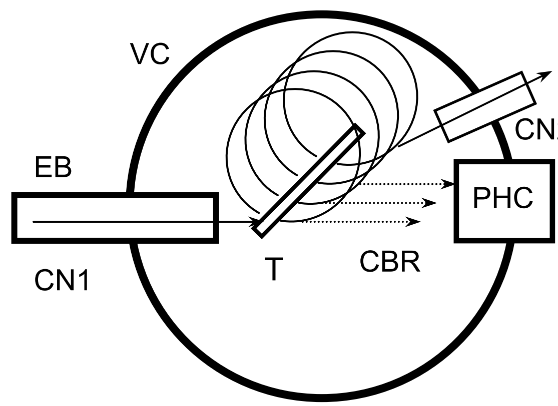

Figure 1.The scheme of experimental setup. VC is a vacuum chamber, T is a crystalline target immersed in a magnetic field, EB is an electron beam, PHC is photon channel for CBR, CH1 and CH2 are channels for injection and removal of electrons.

Here in a vacuum chamber VC a crystalline target T is installed. The target is immersed in a magnetic field. The electron beam EB is injecting through a special channel CH1 in the work volume. Electrons circling in the magnet field are hitting the target several times. Then they are been removed through a channel CH2. CBR generated by electrons is been taken out through a photon channel PCH.

A gist of proposal is to force electrons to do stable multiple crossing of target after preceded ones. For this the special configuration of magnetic field is considered. Here a magnetic field must carry out two functions. The first one is ensuring a stable circulation of electrons with its properly focused fall on the target. The second one is a necessity to shift the rotating particles along the target. A suitable field configuration can be creating by means of magnetic poles of a simple form. These are two parallelepipeds placed over and below the target and stretched along it. The poles are slightly shifted across target plane. In this case the fields dispersed on pole ridges are ensuring spatial focusing of circling particles. Due to a displacement of poles, mean magnitudes of fields are not equal left and right the target, and the latter provides a lateral drift of particles.

It is necessary to notice that the magnet system must provide a special focusing of electron motion. The electron must return on target along the trajectories which should be parallel to initial one. Only in this case an electron motion does not “accumulate” the scattering angle in consequence crossing of a target.

Testing results of proposed scheme, performed by electron motion simulation on the basis of GEANT program library [7], can be illustrated by data in Fig.2 [6].

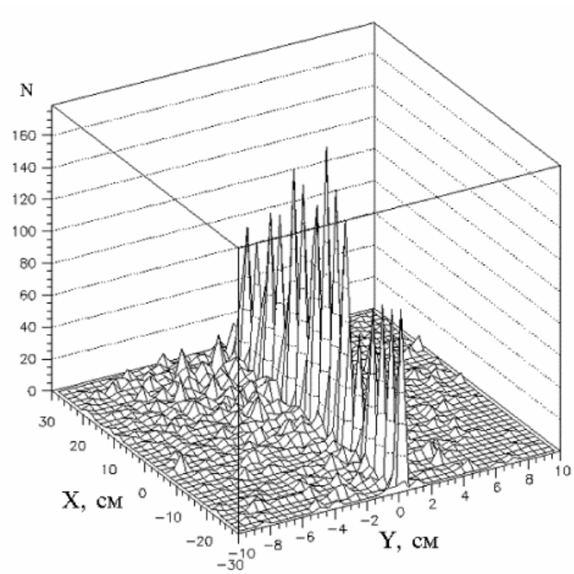

Figure 2. Spatial distribution of intersection points of circling electron trajectories with a target plane (demonstration test with the increased step of cross drift of 5 – MeV electrons in 30 mkm silicon target;). X-axis is vertically directed; Y-axis is stretched along a target.

By this data, the particles can make some tens circulations, and not less than one- two tens of revolutions are made within the limits of a demanded angle of radiation (see above the relation (7)). The latter permits to hope that the scheme proposed allows to rise CBR intensity up to an order. Of cause this scheme can be applied for electrons with low relativistic energy where an “angle conditions” and the requirements to the magnet system are not so hard.

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