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Coherent radiation recoil effect for the optical diffraction radiation beam size monitor at SLAC FFTB

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Abstract

A short electron bunch with length σ passing through a slit in the diffraction radiation (DR) target generates radiation with a broad spectrum. Optical part of the spectrum (incoherent radiation) may be used for beam size measurements, but in the wavelength range $\lambda \geqslant \sigma$ radiation becomes coherent. The coherent DR spectrum per each electron in a bunch is equal to single electron spectrum times by the number of electrons in a bunch N_e and bunch form factor.

For SLAC FFTB conditions ($N_e \sim 10^{10}$, $\sigma = 0.7$ mm, outer target size $R \sim 10$ mm, slit width $h \sim 0.1$ mm) we approximated coherent DR (CDR) spectrum by coherent transition radiation (TR) one because in the wavelength region $\lambda \sim \sigma \gg h$ TR and DR spectra coincide with high accuracy. Changing the DR target by a TR target with projection on the plane perpendicular to electron beam as a circle with radius $R \leqslant 20$ mm we calculated CDR spectra using simple model.

Knowing the CDR spectrum we estimated the energy CDR emitting by each electron in the perpendicular direction (due to target inclination angle 45°). It means an electron receives the radiation recoil in this direction. In other words, electron has a transverse kick about 1 μrad that may be considered as permissible.
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Optical transition radiation is recently widely used for diagnostics of the beams [1]. However, the direct interaction of beam particles with the target material may cause its transformation and distortion of optical characteristics, and for intense focused beams even destruction of the target [2]. When the beam of ultrarelativistic electrons passes in a vacuum near the conductive target the so-called diffraction radiation (DR) is generated, which features allow using it for non-invasive beam diagnostics [3,4]. In [5] we proposed to use the optical DR to create beam size monitor at SLAC Final Focus Test Beam, where the intensity of electron beam is $(1–3)\times 10^{10}$ particles/ bunch with FWHM bunch length equal to 0.7 mm. In this case there is a need to estimate the possible distortions of the beam characteristics due to wakefield deflection.

This effect is connected with two kinds of short bunch interaction with conductive target:

- geometric wakefield [6];
- resistive wakefield [7].

DR target is made of the highly conductive material that is why the geometric wakefield determines the major impact.

The consideration given in [8] shows that the geometric wakefield effect may be interpreted as a recoil effect due to coherent DR. This is shown in Fig. 1. During the passing of the electron through the slit in the inclined target the intrinsic Coulomb field of the particle is reflected from the surface of the target and is transformed into the real photons of DR, which emitted in the cone with an apex angle $\sim\gamma^{-1}$ along the direction of the mirror reflection. For the target inclination angle $\psi = 45°$ DR is emitted at right angle to the electron momentum (backward diffraction radiation, BDR).

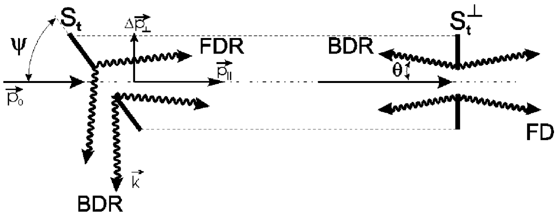

Fig. 1. Generation of forward (FDR) and backward diffraction radiation (BDR) from inclined and perpendicular target.

Real photons of BDR, having a certain momentum in the specular reflection direction $k_\perp = \frac{W_{\rm DR}}{c}$ ($W_{\rm DR}$ the total BDR energy losses, c-speed of light), transfer momentum to electrons $|\Delta\vec{p}_\perp| = k_\perp$ (recoil effect). Just this reason leads to beam deflection. The estimation of an electron deflection angle based on the described approach [8] agrees with result obtained from the geometric wakefield model [6]. In order to estimate the radiation losses in the BDR cone we will use the following assumptions:

- perfect conductive target;
- BDR energy from the inclined target with the surface $S_{\rm t}$ equal to BDR energy from the perpendicular target with the surface $S_{\rm t}^\perp = S_{\rm t}\sin\Psi$ (see Fig. 1).

Authors of [9] pointed out that DR energy losses for a particle moving near a tilted semi-infinite perfect screen are defined by its projection on the plane perpendicular to the particle trajectory. For an ultrarelativistic case DR energy losses were calculated in [10] where no dependence on a tilted angle Ψ was obtained if condition $\Psi \gg \gamma^{-1}$ is fulfilled. One may assume that for a slit DR target there is the same situation.

The simplest model of DR from ultrarelativistic particle for the perpendicular target with the finite square (DR for a disk with the hole) is described in [11]. Spectral-angular distribution of DR in such target is described with the following formula:

$$\frac{{\rm d}W_{\rm BDR}}{{\rm d}\omega\,{\rm d}\Omega} = \frac{\alpha\hbar}{\pi^2}\frac{\theta^2}{\left(\gamma^{-2}+\theta^2\right)^2}\cdot\left\{\frac{\omega R_{\rm out}}{\gamma c}K_1\left(\frac{\omega R_{\rm out}}{\gamma c}\right)J_0\left(\frac{\omega R_{\rm out}\theta}{c}\right) - \frac{\omega R_{\rm in}}{\gamma c}K_1\left(\frac{\omega R_{\rm in}}{\gamma c}\right)J_0\left(\frac{\omega R_{\rm in}\theta}{c}\right)\right\}^2. \quad (1)$$

Here α – fine structure constant; $\hbar$ – Planck's constant; θ – BDR photon outgoing angle; ω – photon frequency; γ – Lorentz factor; $R_{\rm out}$ – outer radius of the disk; $R_{\rm in}$ – radius of the hole; $K_1(x)$, $J_0(x)$ – Bessel functions.

Formula (1) is written for incoherent radiation of electron. During the generation of BDR by