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Focusing of transition radiation and diffraction radiation from concave targets

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Abstract

In the article the transition radiation from a relativistic charge crossing a finite radius paraboloid target with taking into account the pre-wave zone effect is considered. It is shown that in this case the radiation cone narrowing occurs in contrast with the transition radiation from the flat target if the detector is situated at the distance, which is smaller than the focus distance (the focusing effect) from the target. At the charged particle passage through the central hole in a paraboloid target the diffraction radiation focusing (DR) occurs too. The focusing of coherent DR for the non-invasive measuring of the electron bunch length is proposed.

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1. Transition radiation (TR) is widely used for an electron beam diagnostics. For instance, in the experiment [1] for measurements of the transverse size of an electron beam, the optical transition radiation focusing system allowed the spatial resolution to be reached at about ~5 μm. In the work [2] an electron bunch length was measured using the spectrum of coherent transition radiation (CTR). The alternative approach was demonstrated by the authors of work [3], where the CTR beam was being generated by the bunch of the length of about $l_b \sim 1$ mm, then it was being focused by the complicated optical system on the electro-optical crystal, through which the linear-polarized radiation of a stable laser passed. The crystal becomes birefringence under the influence of electric field $\vec{E}_{CTR}$ that leads to the circularly-polarized component occurrence in the laser radiation after the crystal with degree ΔP_C the value of which is in proportion to the field $\vec{E}_{CTR}$ and spill time Δt:

$$\Delta P_C \sim |\vec{E}_{CTR}|\Delta t \sim |\vec{E}_{CTR}| l_b / c. \tag{1}$$

The bunch length l_b was determined from the value ΔP_C measured. The using of TR – target for diagnostics leads to a beam emittance growth in avoidable.

The non-invasive diagnostics based on the diffraction radiation use was developed in the works [4,5]. We can suggest the diagnostics scheme, which is analogous to the scheme used in the experiment [3] where instead TR, the diffraction radiation (DR) is generated by the electron beam passing through the hole of the concave target (see Fig. 1). In this case, firstly, the diagnostics becomes practically non-invasive, secondly, DR focusing by the target itself simplifies the experimental equipment (there is no necessity to have a focusing system) and thirdly, increases the technique sensitivity because the field intensity of focused radiation from the concave target exceeds the field intensity from the flat one.

Actually, as it was mentioned in work [6], the virtual photon field of ultrarelativistic charge is close to transverse field of electromagnetic wave by its characteristics. The virtual photon field, in analogy with electromagnetic wave,

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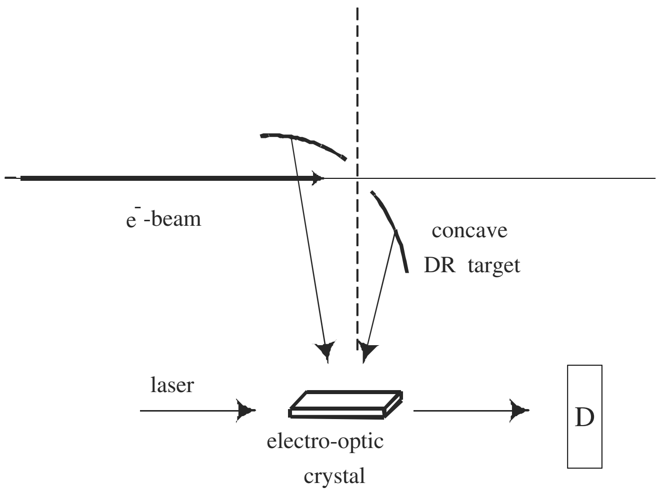

Fig. 1. Scheme of experiment.

bends around the screen of the finite sizes, that is the origin of DR occurrence. So, we can suppose that for the parabolic target the focusing effect in transition and diffraction radiation of ultrarelativistic particles must exist.

In the series of works [7–9], the models for TR characteristics calculation were developed for the deformed targets of the finite sizes. In our paper, the approach which allows taking into account the influence of the finite size [10,11], the pre-wave zone effect [12] and the "global" form of the deformed target (for examples, paraboloid), but not a "local" one as in works [7,9] has been developed.

Besides, the suggested approach allows both the characteristic of TR and DR to be calculated. As in the cited works, the perfectly conducting target is considered.

2. Let us consider the diffraction radiation in the pre-wave zone using the model developed in [13]. For the simplicity of calculations, let us choose the geometry when the relativistic electron with the constant velocity v passes near the semi-infinite plane with almost zero impact parameter when the target is inclined from the perpendicular position at angle of $\alpha \sim \gamma^{-1} \ll 1$ (see Fig. 2). The field of the backward DR may be calculated on the detector plane from the expression:

$$\begin{Bmatrix} E_x^{\mathrm{D}}(X_{\mathrm{D}}, Y_{\mathrm{D}}) \\ E_y^{\mathrm{D}}(X_{\mathrm{D}}, Y_{\mathrm{D}}) \end{Bmatrix} = \mathrm{const} \int \mathrm{d}X_{\mathrm{T}}\,\mathrm{d}Y_{\mathrm{T}} \begin{Bmatrix} X_{\mathrm{T}} \\ Y_{\mathrm{T}} \end{Bmatrix} \times \frac{K_1\left(\frac{k}{\beta\gamma}\sqrt{X_{\mathrm{T}}^2 + Y_{\mathrm{T}}^2}\right)}{\sqrt{X_{\mathrm{T}}^2 + Y_{\mathrm{T}}^2}} \exp[\mathrm{i}\Delta\varphi]. \quad (2)$$

In (2) variables with indexes T, D are described the coordinates reference in the system on the target and detector surfaces respectively, $\Delta\varphi$ is the radiation phase shift, K_1 is the second kind Bessel modified function, the $k = \frac{2\pi}{\lambda}$ is the wave vector, λ is the radiation wavelength, $\beta = v/c$ and γ is the Lorentz-factor.

The calculations will be made in the dimensionless variables:

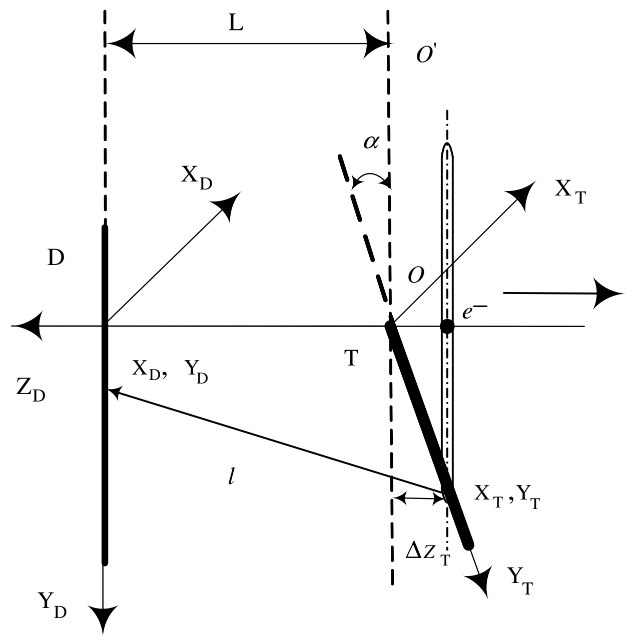

Fig. 2. To the calculation of phase shift; the electron passes near target with zero impact parameter.

$$\begin{Bmatrix} x_{\mathrm{T}} \\ y_{\mathrm{T}} \end{Bmatrix} = \frac{2\pi}{\gamma\lambda} \begin{Bmatrix} X_{\mathrm{T}} \\ Y_{\mathrm{T}} \end{Bmatrix}, \quad \begin{Bmatrix} x_{\mathrm{D}} \\ y_{\mathrm{D}} \end{Bmatrix} = \frac{\gamma}{L} \begin{Bmatrix} X_{\mathrm{D}} \\ Y_{\mathrm{D}} \end{Bmatrix}, \quad R = \frac{L}{\gamma^2\lambda}. \quad (3)$$

Here L is the distance from the target to the detector.

The integration in (2) is performed on the target surface, which can be limited.

As it has been mentioned in article [12], the "DR source" at the distance $L \leqslant \gamma^2\lambda$, cannot be considered on the target surface as a pointwise one. In other words, for large-size dimensionless parameter $R = L/\gamma^2\lambda \gg 1$, the DR (or TR) characteristics can be described as angular distributions from the pointwise source (so-called far zone), while at $R \leqslant 1$ the "pre-wave zone effect" [12] plays the important role in the cases where the natural size of the "luminous" target area, which is defined order by the size parameter $\gamma\lambda$, should be taken into account. In this case (especially at $R \ll 1$) it is more natural to describe DR (TR) characteristics as coordinate distributions, for example, on the detector's surface.

The phase shift $\Delta\varphi$ in the expression (2) will be calculated relative to the plane OO′ (see Fig. 2).

$$\Delta\varphi = \frac{2\pi\left(l + \frac{\Delta Z_{\mathrm{T}}}{\beta}\right)}{\lambda} = \frac{2\pi}{\lambda} \times \left[\sqrt{(Y_{\mathrm{T}}\cos\alpha - Y_{\mathrm{D}})^2 + (X_{\mathrm{T}} - X_{\mathrm{D}})^2 + (L + \Delta Z_{\mathrm{T}}(X_{\mathrm{T}}, Y_{\mathrm{T}}))^2}\right] + \frac{2\pi}{\lambda}\frac{\Delta Z_{\mathrm{T}}(X_{\mathrm{T}}, Y_{\mathrm{T}})}{\beta}. \quad (4)$$

Here l is the distance between the point on the target $(X_{\mathrm{T}}, Y_{\mathrm{T}})$ (the point where the spherical wave emitted) and the point on the detector $(X_{\mathrm{D}}, Y_{\mathrm{D}})$, $\Delta Z_{\mathrm{T}} = Y_{\mathrm{T}}\sin\alpha$ (see