UV AND X-RAY DIFFRACTION RADIATION FOR SUBMICRON NONINVASIVE DIAGNOSTICS*

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Abstract

In the present work DR from the bunch of ultrarelativistic charged particles at X-ray and UV frequencies domains is explored theoretically. It is shown that incoherent part of form-factor, describing the effect of *N* electrons in bunch, exists and differs from the unit. The coherence effects are proved to be important up to the wavelengths much less than longitudinal size of the bunch. The theory developed open the possibility to diagnose bunches of the submicron size with very high accuracy.

INTRODUCTION

Interest to the diffraction radiation increases in recent years due to the possibility of creating new powerful sources and the possibility of noninvasive bunches diagnostics. Noninvasive diagnostics is already used at facilities in Japan, Germany, USA. In this scheme there is no modifying of the beam properties.

Diffraction radiation (DR) arises when a charged particle moves above the target. The nature of DR is the radiation arising due to the dynamic polarization of the material by the Coulomb field of the passing charge.

The theory of X-ray and UV radiation from the single particle had already been developed in [1, 2]. In this work the X-ray and UV DR from the bunch of charged particles is discussed.

DIFFRACTION RADIATION AND INCOHERENT FORM-FACTOR

We consider the *N* particles moving at the distance *h* from the edge of the target of width *a* (See Fig. 1). All the particles have a charge *e* and move with constant velocity $\mathbf{v}=(v,0,0)$.

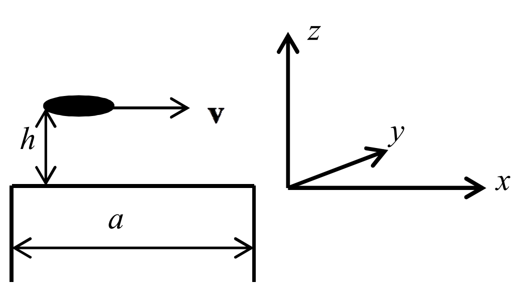

Figure 1: Geometry of the passage of the charged particle in the process of DR generating.

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Knowing the Coulomb field of a single particle and using the polarization current method, described in detail in [3, 4], one can get the expression for the radiation field $\mathbf{E}(\mathbf{r},\omega)$ and the expression for the spectral-angular distribution [3]:

$$\frac{d^2W_N(\mathbf{n},\omega)}{d\Omega d\omega}=\frac{d^2W_1(\mathbf{n},\omega)}{d\Omega d\omega}F\,. \tag{1}$$

Here $\frac{d^2W_1(\mathbf{n},\omega)}{d\Omega d\omega}$ is the spectral-angular distribution of the radiation from the single particle:

$$\frac{d^2W_1(\mathbf{n},\omega)}{d\Omega d\omega}=\left(\frac{\varepsilon(\omega)-1}{v\varphi}\right)^2\frac{\omega^2}{c^2}\frac{ce^2}{4\pi^2}\sin^2\left(\frac{a\varphi}{2}\right)Be^{-2\rho h} \tag{2}$$

$$B=\left(1-n_z^2+\frac{\mathbf{A}^2-(\mathbf{nA})^2}{\rho^2}\right)\Big/\left(\beta^{-2}\gamma^{-2}+\varepsilon n_y^2+\varepsilon n_z^2\right)$$

and

$$F=\left\langle\left|\sum_{n=1}^{N}e^{-i\xi x_n}e^{-ik_y y_n}e^{-\rho z_n}\right|^2\right\rangle \tag{3}$$

is the form-factor of the bunch; $\langle\ldots\rangle$ stands for averaging over the locations of all the particles, N is the number of particles.

Usually the expression for the form-factor *F* is written as:

$$F=N+N(N-1)G\,, \tag{4}$$

but in fact the situation is more complicated. In our work [6] it was demonstrated that the correct form-factor is

$$F=NG_{incoh}+N(N-1)G_{coh}\,. \tag{5}$$

We consider the cylindrical bunch with the radius r_0 and length *l*. It is also supposed that the particles are distributed uniformly. The hard-edged, uniformly filled bunches have been investigated for a long time [5], and recently have been observed [6]. After calculating the expressions for incoherent and coherent parts of the form-factor take the form:

$$G_{incoh} = 2I_1\left(2\rho r_0\right)/\left(2\rho r_0\right)$$

$$G_{coh} = \frac{4\sin^2\left(\frac{\omega}{2v}l\right)}{\left(\frac{\omega}{2v}l\right)^2}\frac{I_1^2\left(\frac{\omega}{c\beta\gamma}r_0\right)}{\left(\frac{\omega}{c\beta\gamma}r_0\right)^2} \qquad (6)$$

Here $I_1\left(z\right)$ is the modified Bessel-function of the first kind, $\rho^2 = \left(\frac{\omega}{c\beta\gamma}\right)^2 + k_y^2$. [7]

ANALYSIS

One can see that G_{incoh} differs from the unit. One can find the optimal parameters in order to demonstrate when difference is pronounced. The Fig. 2 demonstrates this difference for parameters of SLAC. However, if we take the bunch radius smaller, the difference disappears (see Fig. 3). All the graphs are plotted for $n_y = 0$.

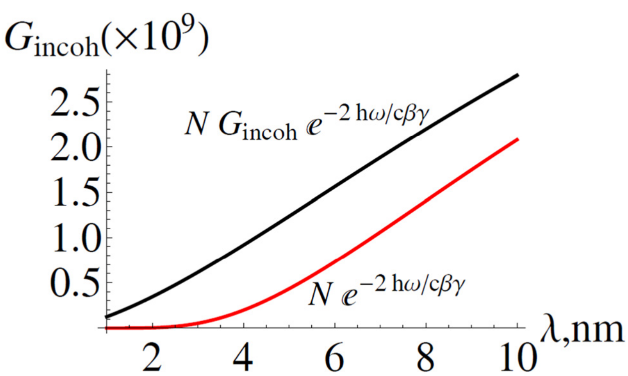

Figure 2: $\gamma = 4\cdot10^4$, $r_0 = 50\,\mu m$, $N = 10^{10}$ $h = 55\,\mu m$.

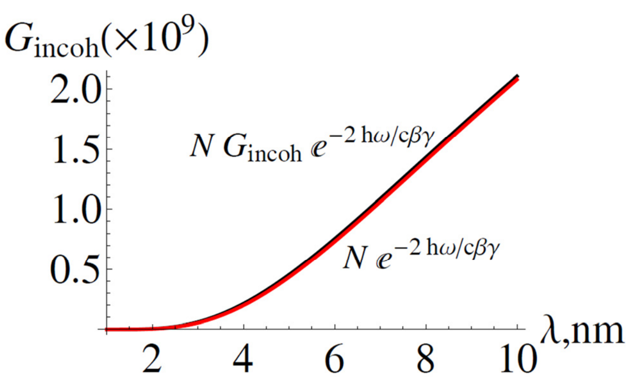

Figure 3: $\gamma = 4\cdot10^4$, $r_0 = 10\,\mu m$, $N = 10^{10}$, $h = 55\,\mu m$.

The behavior of the incoherent and coherent form-factor parts is shown on Fig. 4. One can see that the incoherent part dominates starting from rather small wavelengths. It is important that the incoherent form-factor is noticeable for. This $\lambda << l$ opens opportunity for diagnostics of the bunches of submicron size with very high accuracy.

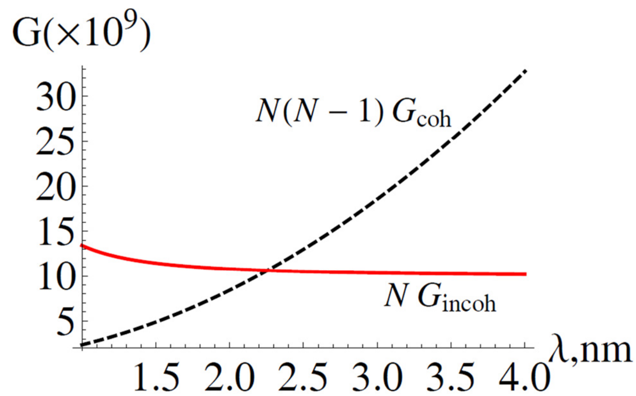

Figure 4: $l = 50\,\mu m$, $r_0 = 5\,\mu m$, $N = 10^{10}$, $h = 10\,\mu m$, $\gamma = 4\cdot10^4$.

The curve corresponding to the coherent part of radiation crosses the incoherent in “water window” wavelength region (2.3-4.4 nm). In this region the attenuation length is rather high for water, which is especially important for medicine and biology.

We considered the dependence of the incoherent form-factor on the radius of the bunch in X-ray and UV region. Figure 5 demonstrates that for G_{incoh} not equal to the unit the intensity of radiation is greater. The difference between G_{incoh} and the unit increases with growing r_0 .

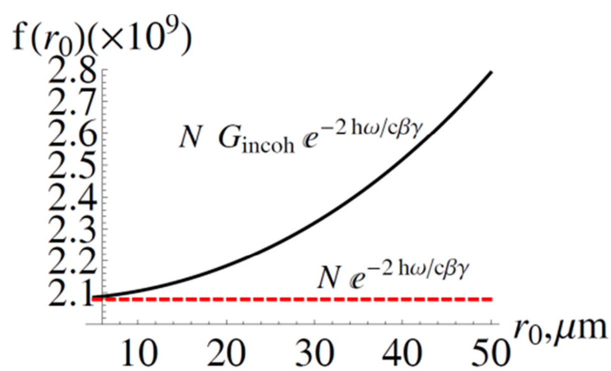

Figure 5: $\gamma = 4\cdot10^4$, $\lambda = 10\,nm$, $h = 50\,\mu m$, $N = 10^{10}$.

Figures 6, 7 demonstrate the behavior coherent and incoherent parts of spectral-angular distribution of DR for parameters of the high energy future facilities (for example, for ILC $\gamma = 10^6$).

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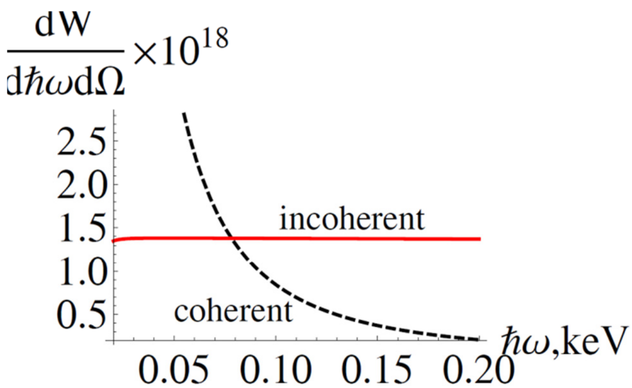

Figure 6: $l = 0.3\,nm$, $a = 5\,nm$, $N = 0.75\cdot 10^{10}$, $h = 5\,\mu m$.

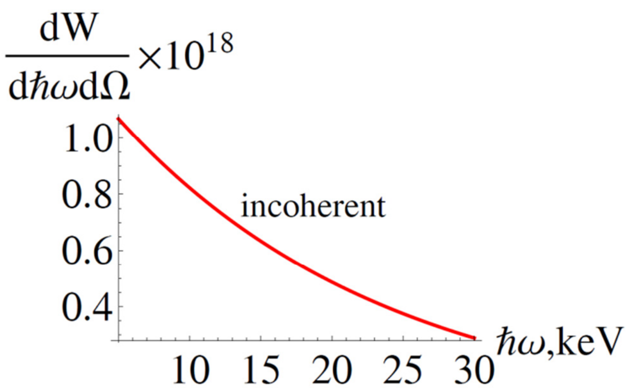

Figure 7: $l = 0.3\,nm$, $a = 5\,nm$, $N = 0.75\cdot 10^{10}$, $h = 5\,\mu m$.

CONCLUSION

So, the theory of shortwave diffraction radiation is developed for UV and X-ray frequency ranges. This theory is of real importance for noninvasive submicron beam diagnostics. The incoherent form-factor is proved to exist. Above we demonstrated that at some conditions the difference between the incoherent form-factor and the unit is considerable.

It was demonstrated also that coherent form-factor depends on transversal size of the bunch for $\lambda << l$.

The cut-off frequency $\omega_c = \gamma c/h$ increases with the growth of Lorentz-factor γ, i.e. the spectrum of DR extends in to UV and X-ray domains up the frequency ω_c (See Fig. 7).

This fact is appreciable especially for future super high energy colliders like ILC and CLIC (but also might be of use for smaller energies like $\gamma = 10^3 - 10^4$). Therefore, the theory developed will be especially useful for diagnostics of their beams and for the describing bunches dynamics.

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