

A NEW APPROACH FOR THE ELECTRON BEAM DIAGNOSTIC USING DIFFRACTION RADIATION DISPHASE TARGET*

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Abstract

The approach to calculate characteristics of diffraction radiation (DR) from a disphase target is developed. The results of simulation of the DR spatial distribution on a detector surface for the fixed wavelength are shown and its feasibility for non-invasive beam diagnostics is discussed.

INTRODUCTION

Since 1995, when the diffraction radiation (DR) from relativistic particles was first observed [1], the development of new approaches using the DR for charged particle beam non-invasive diagnostics is continued. The DR is a radiation which appears when charged particle moves close to the media and only the electromagnetic field interacts with it. A rather well-known in scientific accelerator community the non-invasive diagnostic method of transversal bunch size is to use a slit target [2]. The non-invasive manner to monitor the charge particle beam is great advantage of DR target in contrast with transition radiation target. Nowadays there are a few type of DR target in addition to slit target, for example, single plate and double slit target or double DR target interferometry [3-5].

The disphase target consists of the two rectangular flat plates inclined with respect to each other at an angle compared with $1/\gamma$, where γ is the Lorentz-factor (see Fig. 1) [6, 7].

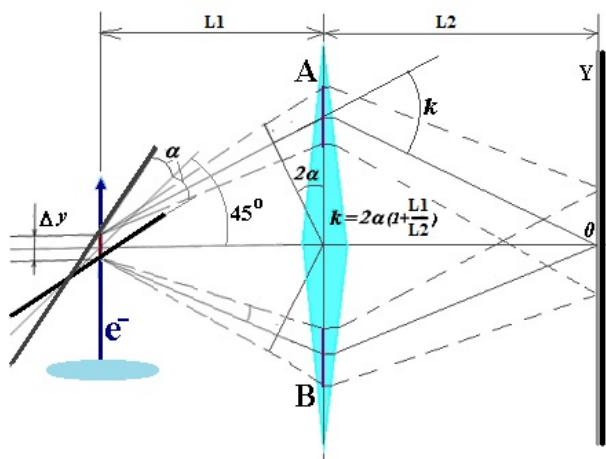


Figure 1: Optical scheme of image obtaining.

The lens “AB” produces an interference pattern in the detector. One can expect the pattern characteristics

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(“visibility” and so on) will depend on a beam size and the sensitivity is determined by the Lorentz-factor γ and inclination angle α . We have developed the theoretical model describing the scheme presented in Fig. 1, including such effect as pre-wave zone, finite size of target and lens characteristics. Our approach which based on the pseudophoton method [8] is allowed to obtain an interference pattern on a detector after 4-dimensional integration.

The lens properties and radiation propagation downstream a lens consider in the frame of the wave optics [9]. The code to simulate the spectral-spatial distribution of DR in the pre-wave zone from disphase target (without lens) was developed before [10]. Later this code was modified and adapted for another task [11].

In this report we present the further research and simulation results characterizing an applicability of the disphase target for beam diagnostics.

SIMULATION APPROACH

The results of the previously developed code which based on the pseudophoton approach were tested by comparing the results obtained on the generalized surface current method [12]. All spectral-spatial distributions for the case of transition radiation, DR from slit target and DR from disphase target are in a good agreement with more accurate but time-consuming calculation [12]. That testing was performed without a lens. Then the code was further modified in order to take into account the focusing effect of the lens. Modification was done in following way. First, the spectral-spatial distribution $E_{x,y}^L(r_L, \lambda)$ was calculated on the lens surface at given points. The surface of the lens is selected such that the radiation distribution (peaks and surroundings which mainly depends on the disphase angle) was got into the integration region for given target-to-lens distance. Second, on the base of this distribution the interpolation function was constructed. Finally, the spectral-spatial distribution on the detector (or image) plane $E_{x,y}^D(r_D, \lambda)$ was calculated by formula:

$$E_{x,y}^D(r_D, \lambda) = \iint [E_{x,y}^L(r_L, \lambda)]_{int} \cdot e^{-\frac{ik}{2f}(x_L^2 + y_L^2)} \cdot \frac{e^{ik|r_D - r_L|}}{|r_D - r_L|} dS_L$$

Where $r_L = \{x_L, y_L, z_L\}$ and $r_D = \{x_D, y_D, z_D\}$ are the coordinate on the lens and detector surface respectively, λ is the radiation wavelength, $k = 2\pi/\lambda$ is the wave number, $|r_D - r_L|$ is the distance between the points on the detector and the lens, S_L is the lens surface and $[E]_{int}$ is the interpolation function of the DR distribution. The finite value of S_L is equivalent to the finite aperture of the

lens. The second term of the integrand describes the infinitely thin lens. The third one describes the free space radiation propagation to the detector from the lens.

The simulation code was written on the base of Wolfram Language. Before starting the main stage of simulation, the test calculation without and with lens was done for transition radiation target with the same parameters as for the disphase target. The result shows a good agreement with a point spread function calculations.

SETUP DESCRIPTION

Hereinafter the parameters of the target, lens and electron beam are listed in Table 1 which takes place in our simulation.

Table 1: Simulation Parameters

Name	Value
Electron energy, E_e	1.28 GeV ($\gamma \approx 2505$)
Wave length, λ	558 nm
Target dimensions ($\Delta x, \Delta y$)	$3 \times 3 \text{ mm}^2$
Slit width, a	0.425 mm
Disphase angle, 2α	6.2 mrad
Target tilt angle, θ_0	$\pi/4$
Target-to-lens distance, L_1	30 cm
Lens-to-detector distance, L_2	15 cm
Lens focal distance, f	15 cm

For those parameters we may see that the effective electron field is equal about 1.4 mm, the distance which corresponds to the far-field zone should be more than 3.5 m. Note that x-direction is across a slit and y-direction is along a target slit. A disphase angle is the angle between two plates of target. It means that tilt angle for one plate is equal to $\theta_0 - \alpha$ and $\theta_0 + \alpha$ for another one. The lens-to-detector distance equal to $L_2 = f$ corresponds to the case of angular distribution measuring on the image plane.

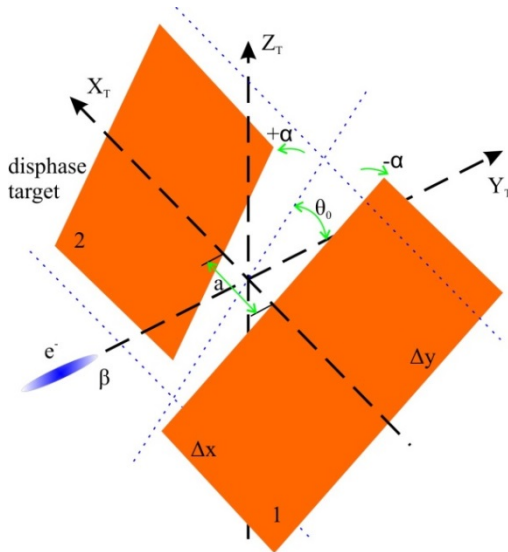


Figure 2: 3D disphase target model.

In Fig. 2 the 3D disphase target model is presented in more details with necessary notation. Note that for the 45° -tilt angle of the target in such a scheme the backward DR propagates along z-axis. Also point out that such small target size was chosen to reduce the computation time. However, this does not change the conclusions which are made in the end.

RESULTS AND DISCUSSION

The view of spatial radiation distribution for the disphase target considerably differs from generally known view of TR and DR distribution from the flat and slit target respectively. Those spatial distributions along two cross-sections in comparison with DR ones are shown in Fig. 3.

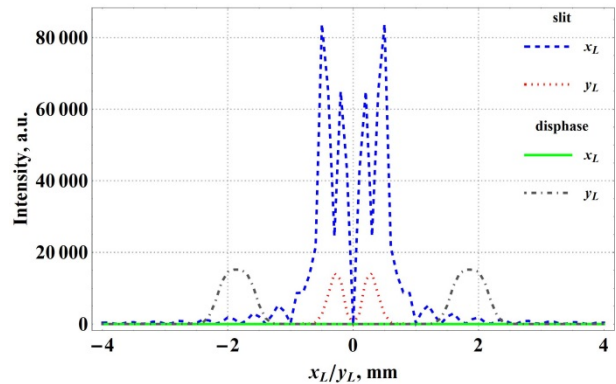


Figure 3: Cross-section of the spectral-spatial distributions of DR from the slit and disphase targets on the lens surface at $L_1 = 30 \text{ cm}$ (section along x-axis and y-axis). Here target dimensions were $1 \times 1.5 \text{ mm}^2$.

As expected, the distribution from disphase target has not the interference structure and consists of two cones which propagate to the lens from both plates of this type of a target. Quantitatively the peaks positions match with the predicted values: $L_1/\gamma \approx 0.12 \text{ mm}$ for slit target and $L_1 \cdot 2\alpha \approx 1.86 \text{ mm}$ for disphase target.

The DR distribution from the disphase target in more details is presented in Fig. 4 for the same simulation parameters as in Fig. 3. Those two figures depict data which contain the full sum of radiation components $|E_x|^2$ and $|E_y|^2$.

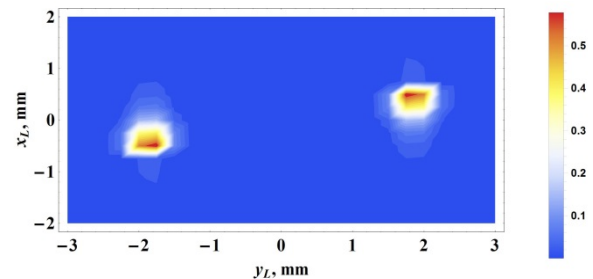


Figure 4: Spectral-spatial distributions of DR (a. u.) from the disphase target on the lens surface.

Figure 5 and 6 show two cross-sections of the distributions of DR from the disphase target on the detector.

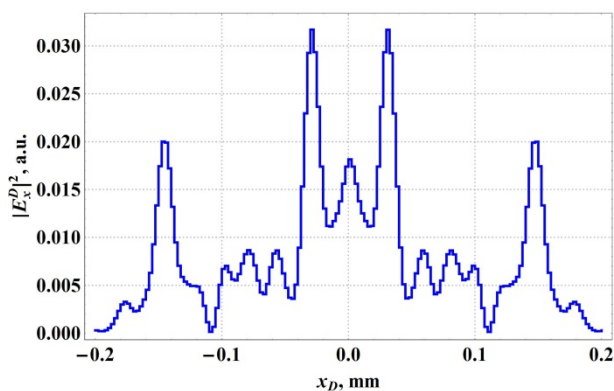


Figure 5: 2D distributions of DR from the disphase target on the image plane for $L_2 = 15$ cm (section along x-axis).

The distributions are represented only for $|E_x|^2$ component of the radiation. It was done to speed up the calculations because of another component is several times smaller ($|E_y| < |E_x|$). Those curves correspond to the sections across target slit and along slit respectively. One may see that they have clear interference structure but rather complicated one and the pattern was focused by lens into the sub-mm size. Due to such complicated structure and the narrowness of the peaks of the distributions (Fig. 5, 6) we suggest to use a 1D lens (along y-axis only) for a beam diagnostics goal. We may suppose that in this case the interference pattern will have more convenient form in order to analyse it. Thus, the task the additional research is required.

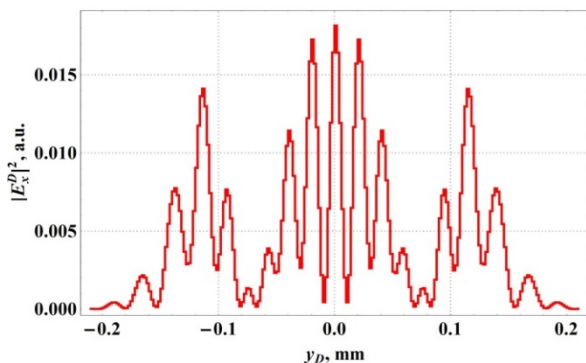


Figure 6: 2D distributions of DR from the disphase target on the image plane for $L_2 = 15$ cm (section along y-axis).

Note that the full sizes of the distributions on Fig. 5 and 6 are appeared to be close to the slit width.

CONCLUSION

At present we may conclude that the rather powerful numerical simulation code was developed which allow computing the DR characteristics from the different type of targets with taking into account pre-wave zone effect, target finite size, lens aperture, the mutual position of the elements in the optical system and an arbitrary trajectory

of a particle between two plates of the target. The code algorithm is based on the direct 4-fold integration when calculating the DR distributions and included the polarization current theoretical model.

The result of imaging of the DR from disphase target through the 2D lens shows the complicated interference pattern. We suppose that such patterns produced by an electron bunch with finite transversal sizes will have a “smoothed” shape and decreasing of “visibility” caused by real bunch sizes. The detailed simulation can allow to choose parameters of DR disphase target in order to reconstruct bunch transversal sizes from a measured pattern with good reliability.

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