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ELECTRON BEAM POSITION MONITOR BASED ON OPTICAL DIFFRACTION RADIATION

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МОНИТОР ПОЛОЖЕНИЯ ПУЧКА УСКОРИТЕЛЯ ПО ОПТИЧЕСКОМУ ДИФРАКЦИОННОМУ ИЗЛУЧЕНИЮ

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Аннотация. *В данной работе было произведено моделирование пространственных распределений интенсивности оптического дифракционного излучения. Было показано, что симметрия этих распределений находится в зависимости от начального положения электрона относительно центра щели при её пересечении. Эта зависимость может быть применена для определения положения пучка по получаемым изображениям оптического дифракционного излучения, что, в свою очередь, делает возможным создание на её основе монитора положения пучка.*

Introduction. Diffraction radiation (DR) is a type of radiation that is emitted when a charged particle travels near the boundary between two media with different permittivity values [1]. A particular case of the mentioned type of radiation, which has potential for practical use, is the case when an electron induces DR emission while passing through a rectangular slit represented by two metal plates or foils. If the particle trajectory lies straight up through the center of horizontal slit spatial intensity distribution of vertical polarization component of optical diffraction radiation (ODR) focused on the detector plane by a lens possesses symmetrical two-lobbed structure. However, the symmetry is violated if an incident particle crosses the slit with some vertical shift from its center (offset). Estimating the value of such violation with the optical system presented in Fig. 1 one can define the initial offset (i.e. apply ODR for so-called beam position monitoring [2]).

Evaluating this difference for various shift values, it is possible to find such dependence that allows determining the initial vertical position of the particle at the moment it passes through the slit plane. Therefore, one can conclude, that in the case of the vertical slit intensity distribution of the horizontal polarization component gives information about the horizontal position of the particle. A method that includes both vertical and horizontal slits can be applied in non-invasive beam position monitors that, in turn, could find application in such accelerator facilities as European XFEL [3]. To estimate how fine the method will fit its potential purposes spatial intensity distributions of ODR in the case of horizontal slit were simulated and the change in the shape of distributions was analysed for a set of different initial vertical positions of the particle.

Research methods. ODR intensity distributions were calculated by using Wolfram Mathematica. For the sake of simplicity, only the vertical polarization component of ODR in the case of the horizontal slit is considered. The following electron beam parameters were chosen for calculation: $\gamma = 2500$, $\lambda = 500$ nm.

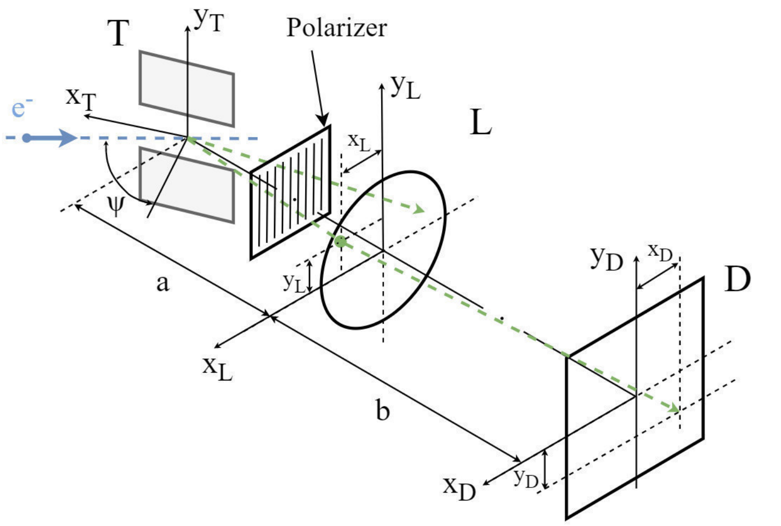

Fig. 1. Scheme of the optical system for ODR focusing consisting of a target represented by a horizontal slit (T), a lens (L), and detector (D)

The calculation for the vertical polarization component of ODR field was carried out by the following formula [4]:

$$E_y^D\left(x_D, y_D, y_0\right) = const \int dx_T dy_T \frac{y_T - y_0}{\sqrt{x_T{}^2 + \left(y_T - y_0\right)^2}} \times$$
$$\times K_1\left(\sqrt{x_T{}^2 + \left(y_T - y_0\right)^2}\right) \exp\left[i \frac{x_T^2 + y_T^2}{4\pi R}\right] \times \left(\frac{4M^2 \sin\left[x_M\left(\frac{x_D}{M} + x_T\right)\right] \sin\left[y_M\left(\frac{y_D}{M} + y_T\right)\right]}{\left(x_D + M \cdot x_T\right)\left(y_D + M \cdot y_T\right)}\right). \quad (1)$$

Following dimensionless units were used in the expression (1): $\left\{x_{T,D}, y_{T,D}\right\} = \frac{2\pi}{\gamma\lambda} \cdot \left\{X_{T,D}, Y_{T,D}\right\}$ are coordinates of the particle on the slit plane; $\left\{x_M, y_M\right\} = \frac{\gamma}{a} \cdot \left\{X_M, Y_M\right\} = \{50, 50\}$ is a lens aperture; $R = \frac{a}{\lambda\gamma^2} = 1$ is a parameter that characterizes far field wave zone [5]; $y_0 = \frac{2\pi}{\gamma\lambda} \cdot Y_0$ is an offset of the incident electron along y-axis of the slit; M is the lens optical magnification, K_1 is the modified Bessel function.

The region of integration for expression (1) is the following: $-5 < y_T < -h$, $h < y_T < 5$, $-5 < x_T < 5$. Here, $h = \frac{2\pi}{\gamma\lambda} \cdot H$ is half of the slit's width, H = 50 μm.

To obtain an expression for intensity distribution of ODR one should use the following expression:

$$I_y^D\left(x_D, y_D, y_0\right) = const \left|E_y^D\left(x_D, y_D, y_0\right)\right|^2. \quad (2)$$

Results. Fig. 2a shows an example of ODR intensity distribution with violated symmetry in its peaks, which is induced by the vertical offset in the electron trajectory relative to the centre of the slit.

Estimating the intensity ratio of main distribution peaks for different vertical positions of an electron within the slit by using expression $\frac{I_{R\max} - I_{L\max}}{I_{R\max} + I_{L\max}}$, where $I_{R\max}$, $I_{L\max}$ are intensity values of right and left peak correspondingly, one can come up with such dependence that allows determining the initial position of the particle within the slit plane at the moment it is crossed. An example of the mentioned dependence is presented in Fig. 2b.

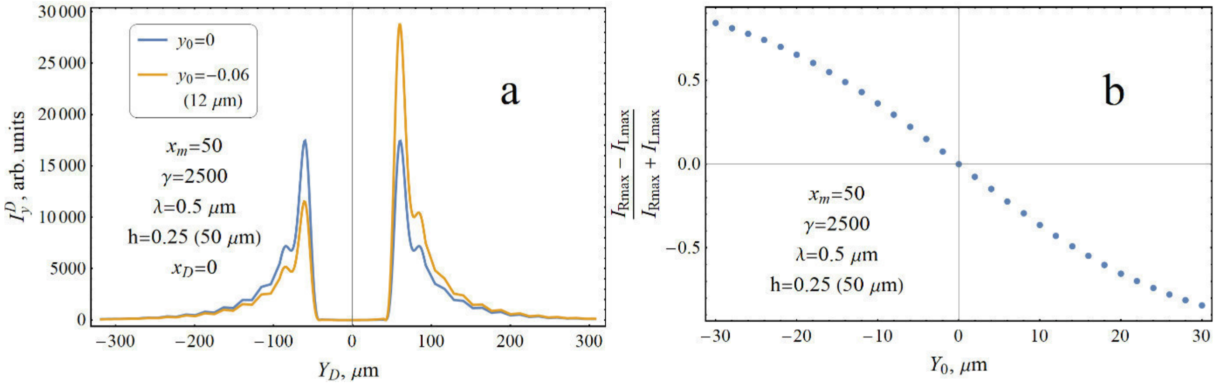

Fig. 2. Asymmetrical ODR intensity distribution of its vertical polarization component in the case of horizontal slit (a); graph that reflects intensity ratio of two main distribution peaks on the initial electron's position along y-axis (b)

Conclusion. The dependence that is shown in the current work allows determining the initial vertical position of the incident electron at the moment it crosses the horizontal slit. However, to obtain the horizontal position of the particle vertical slit should be applied. Although the work only considers a single incident particle its results could be easily extrapolated with a good approximation on the electron beam passing through the slit which width is greater than the beam size. The accuracy of the method suggested here depends on the accuracy in defining the position of distribution peak intensity values (see Fig. 2), which is determined by the wavelength of ODR and lens aperture, and, in the case mentioned above, does not exceed 5%.

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