

# Feasibility of resonant diffraction radiation from inclined gratings for a nondestructive beam diagnostics.

A P Potylitsyn<sup>1</sup>, A R Mkrтчyаn<sup>2,3</sup>, V R Kocharyan<sup>4,5</sup>, A I Novokshonov<sup>6</sup>

<sup>1</sup> Professor, Tomsk polytechnic university, Tomsk, Russia

<sup>2</sup> Professor, Tomsk polytechnic university, Tomsk, Russia

<sup>3</sup> Professor, Institute of Applied Problems of Physics of NAS RA, Yerevan, Armenia

<sup>4</sup> Assistant, Tomsk polytechnic university, Tomsk, Russia

<sup>5</sup> PhD, Institute of Applied Problems of Physics of NAS RA, Yerevan, Armenia

<sup>6</sup> PhD student, Tomsk polytechnic university, Tomsk, Russia

E-mail: novokshonov@tpu.ru

**Abstract.** Characteristics of the resonant diffraction radiation (RDR) generated by ultrarelativistic particles passing near a tilted grating have been considered. Angular distribution of RDR can be used for diagnostics of a beam divergence. Such a technique is non-invasive practically.

## 1. Introduction

One of the known technique for low-emittance electron beam diagnostics is using of optical transition radiation (OTR) which is generated by passing of an electron beam through the thin foil. Obviously that the process of multiply scattering of electrons passing through such a foil makes the emittance worse. Moreover electron beams of modern accelerators with micron transverse sizes interacting with the target can lead to changing of target optical characteristic and that has affected negatively on accuracy of measurements.

Recently years methods of nondestructive diagnostics based on radiation of charged particles in external field (synchrotron radiation, scattering of laser radiation) or on processes of electron Coulomb field scattering during its flight near optical inhomogeneity (diffraction radiation, Smit-Parcell radiation) were developed extensively [1,2]. In this case energy losses of an electron due to radiation only are negligibly small that allows to consider such methods as nondestructive ones.

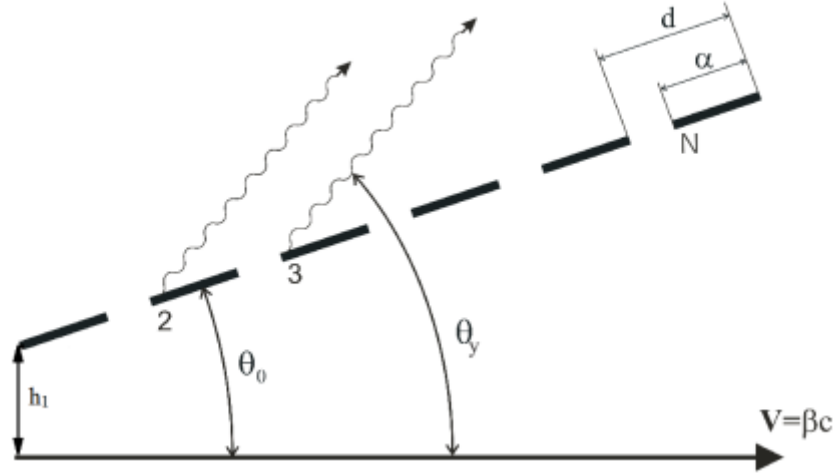
In article [3] authors measured characteristics of optical diffraction radiation (ODR) during the flight of an electron through the slit in the inclined target and they showed possibility of ODR using for a beam transverse size measurements. It is well known that the spectrum of diffraction radiation is continuous. But if the beam is passed in the vicinity conductive target with periodical deformed surface the radiation spectrum contains set of spectral lines with wavelengths depending on observation angle [4].

## 2. Calculations and simulations

In this article we propose to use inclined grating with the period from submicron to millimeters (depends on investigated wavelength range) instead flat slit target. In this case when the resonance condition is fulfilled (see below) there will appear narrow spectral lines in spectrum were line wavelengths will be determined not only by observation angle but the inclined angle of grating too [4].



This fact we suggest to use for the initial beam angular divergence measurements. This is the reason that this radiation can be called the resonant diffraction radiation (RDR).



**Figure 1.** Scheme of resonance diffraction radiation generating.

In Fig. 1 the geometry of RDR generating in the simplest grating is showed. This grating consists of ideal conducting strips with vacuum gaps between. Intensity of radiation for this grating is calculated by the formula [4]:

$$\frac{dW_{RDR}}{\hbar d\omega d\Omega} = \frac{dW_{DR}}{\hbar d\omega d\Omega} F_{strip} F_N, \quad (1)$$

here  $\omega$  is a frequency,  $dW_{DR}/\hbar d\omega d\Omega$  is a spectral-angle intensity of diffraction radiation from flat half-infinite target. The factor  $F_{strip}$  describes diffraction radiation from a single strip:

$$F_{strip} = 4 \cdot (\sinh^2 \alpha + \sin^2 \varphi), \quad (2)$$

$$\alpha = \frac{a\pi \sin \theta_0}{\lambda \gamma} \sqrt{1 + \gamma^2 \theta_x^2}, \quad (3)$$

$$\varphi = \frac{a\pi [\cos(\theta_y - \theta_0) - \cos \theta_0 / \beta]}{\lambda}. \quad (4)$$

Here  $\beta = v/c$  - speed of an electron in units of speed of light,  $\gamma$  - Lorentz-factor,  $\lambda$  - wavelength,  $\theta_0, \theta_y$  are determined in Fig. 1. The projection angle  $\theta_x$  is counted from the plane of figure. For grating consisting of  $N$  periods interference factor  $F_N$  is writing as following:

$$F_N = \exp[-(N-1) \cdot \alpha_0] \cdot \left( \frac{\sin^2(N\varphi_0/2) + \sinh^2(N\alpha_0/2)}{\sin^2(\varphi_0/2) + \sinh^2(\alpha_0/2)} \right), \quad (5)$$

$$\varphi_0 = \frac{2\pi d [\cos(\theta_y - \theta_0) - \cos \theta_0 / \beta]}{\lambda}, \quad (6)$$

$$\alpha_0 = \left( \frac{2\pi d \sin \theta_0}{\gamma \lambda} \right) \sqrt{1 + \gamma^2 \theta_x^2}. \quad (7)$$

It should be noted that a structure of the formula (1) is similar to the formula describing intensity of resonant transition radiation from a stack of foils with taking into account radiation absorption [5].

For a parallel flight ( $\theta_0 = 0$ ) formula (5) becomes the known expression:  $F_N = 2\pi N \delta(\varphi_0 - 2k\pi)$ ,

$$F_N = \frac{\sin^2(N\phi_0/2)}{\sin^2(\phi_0/2)} \rightarrow F_N = 2\pi N \delta(\varphi_0 - 2k\pi), \quad (8)$$

with  $N \rightarrow \infty$ .

As was shown in the work [4] in the case of “long” grating  $N \gg 1$  the generalized dispersion relation connecting wavelength, tilt angle  $\theta_0$  and observation angle  $\theta_y$  can be written in the following manner:

$$\lambda_k = \frac{d \left[ \cos(\theta_y - \theta_0) - \cos \theta_0 / \beta \right]}{k}, \quad (9)$$

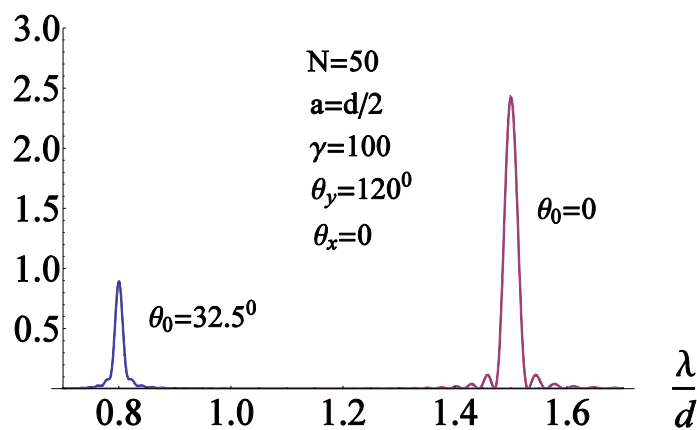
where  $k$  is diffraction order.

Spectral-angular distribution of DR intensity from an inclined perfectly conducting target for charge flying at distance  $h_1$  (see Fig.1) describing by the formula:

$$\frac{d^2 W_{DR}}{\hbar d\omega d\Omega} = \frac{\alpha}{4\pi^2} \exp \left[ -(\omega/\omega_c) \sqrt{1 + \gamma^2 \theta_x^2} \right] \left\{ y^{-2} (1 + \cos \theta_0) \times \left[ 1 - \cos(\theta_y - \theta_0) \right] + \right. \\ \left. + 2\theta_x^2 \left[ 1 - \cos \theta_0 \times \cos(\theta_y - \theta_0) \right] \right\} \left[ (\gamma^{-2} + \theta_x^2) \sin(\theta_y/2) \times \sin^2(\theta_0 - \theta_y/2) \right]^{-1}, \quad (10)$$

Here  $\alpha = 1/137$  is the fine structure constant,  $\omega_c = \gamma c / 2h_1$  is the characteristic frequency of DR.

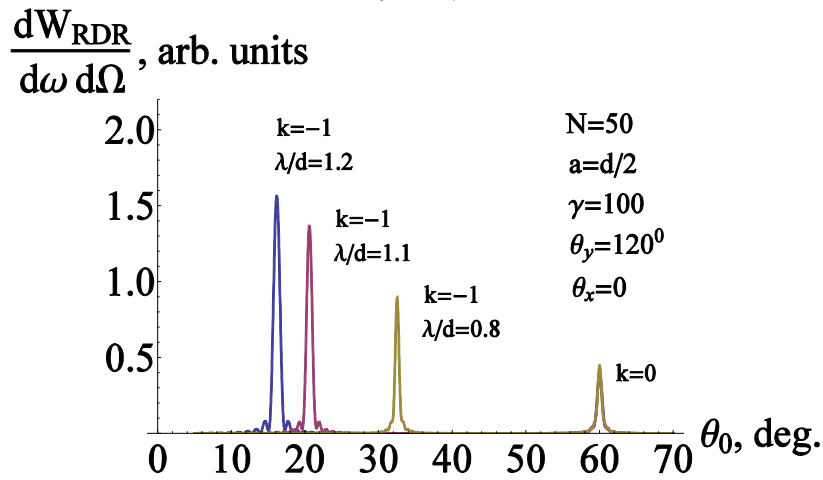
$\frac{dW_{RDR}}{d\omega d\Omega}$ , arb. units



**Figure 2.** Spectrum of RDR for two grating angles  $\theta_0 = 0$  – right one and  $\theta_0 = 32.5^\circ$  with the fixed observation angle  $\theta_y = 120^\circ$ .

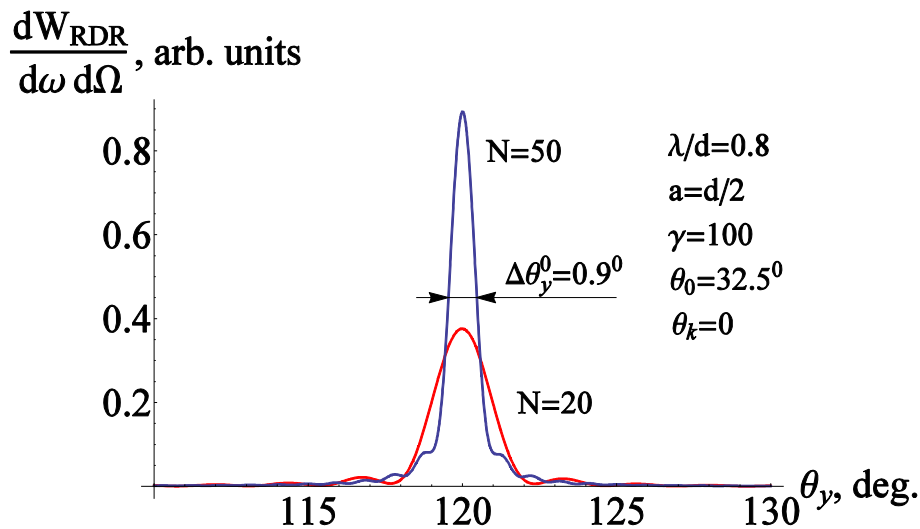
Fig. 2 shows the spectrum of RDR calculated for parameters:  $\omega / \omega_c = 1$ ;  $\gamma = 100$ ;  $N = 50$ ;  $\alpha = d / 2$ ;  $\theta_y = 120^\circ$  for parallel flight of electrons ( $\theta_0 = 0$ , Smit-Parcell radiation) and  $\theta_0 = 32.5^\circ$  (RDR). In both cases quasi monochromatic radiation is generated for the grating with  $N$  periods if the condition  $\gamma\lambda > Nd \cos \theta_0$  is fulfilled:

$$\frac{\Delta\lambda}{\lambda} \sim \frac{1}{N}.$$



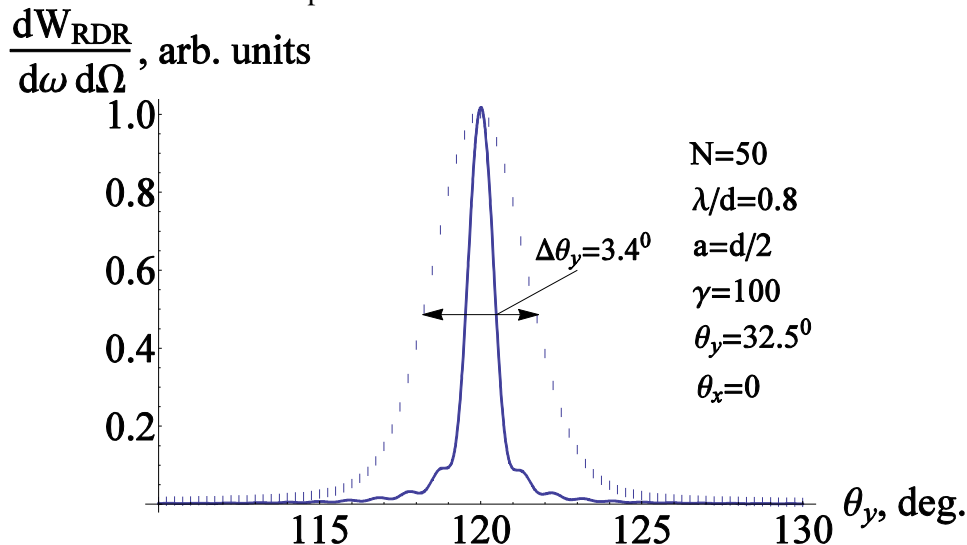
**Figure 3.** RDR intensity dependence on tilt angle  $\theta_0$  for observation angle  $\theta_y = 120^\circ$  and different wavelengths.

On Fig. 3 one can see so-called orientation dependencies – dependencies of RDR intensity with  $\lambda = \text{const}$ ,  $\theta_y = \text{const}$  with changing of grating angle  $\theta_0$ . Three left peaks correspond to diffraction order  $k = -1$  for different wavelengths whereas maximum for  $\theta_0 = 60^\circ$  corresponds to zero order of diffraction ( $k=0$ ) (mirror reflection  $\theta_y = 2\theta_0$ ). Angular distribution of RDR for  $\lambda / d = 0.8$  and  $\theta_0 = 32.5^\circ$  is shown on Fig. 4. Angular width of maximum  $\Delta\theta_y = 0.9^\circ$  for  $N = 50$  can be determined by number of grating periods (condition  $\gamma\lambda > Nd \cos \theta_0$  is satisfied).



**Figure 4.** Angular distribution of RDR for wavelength  $\lambda = 0.8d$  from a grating with number of periods  $N = 50$  and  $N = 20$ .

All results shown above were obtained for an electron beam. Obviously that such a divergence neglecting by angular divergence leads to angular distribution broadening. Simulation results for a beam divergence approximated by the Gauss distribution with parameter  $\sigma = 0.9^\circ$  (16 mrad) is shown in Fig. 5 in comparison with ideal case. Both distributions are normalized to unity. Therefore using of RDR generated during the flight of ultrarelativistic electrons near inclined grating with a reasonable number of periods ( $N = 50$  in this case) allows to measure a divergence of initial beam measuring RDR angular distribution with fixed wavelength. In real conditions of experiment it is possible to use filter with a finite bandwidth. The broadening of RDR angular distribution due to this factor can be simulated without problems.



**Figure 5.** Angular distribution of RDR for wavelength  $\lambda = 0.8d$  from grating with a number of periods  $N = 50$  for ideal electron beam (continuous curve) and for divergent beam ( $\sigma = 0.9^\circ$  - points)

### 3. Conclusion

In conclusion we note that optical transition radiation from optical grating [6] where number of periods is was investigated in experiment for electron beam energy  $E_0$  successfully.

This work was partly supported by the Russian Ministry of Education and Science within the program “Nauka” Grant # 3.709.2014/k

This work was particularly supported by the grant of the Ministry of Education and Science of the Russian Federation within program “Nauka”.

### References

- [1] Smith S.J., Purcell E.M. Phys. Rev. **92** (1953) 1069.
- [2] Potylitsyn A.P., Ryazanov M.I., Strikhanov M.N., Tishchenko A.A. Diffraction radiation from relativistic particles // Berlin: Springer, 2010, 278 p.
- [3] Karataev P., Araki S., Hamatsu R. et al. Phys. Rev. Lett. **93** (2004) 244802.
- [4] Potylitsyn A.P., Karataev P.V., Naumenko G.A. Phys. Rev. E. **61** (2000) 7039.
- [5] Garibyan G.M., Shi Ian. X-ray transition radiation. Erevan, Academy of Science USSR, 1983.
- [6] Henry P., Haeberle O., Rullhusen P. Phys. Rev. E. **60** (1999) 6214.