A VAVILOV-CHERENKOV RADIATION IN THE PASSAGE OF A CHARGE NEAR A DIELECTRIC PRISM

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ИЗЛУЧЕНИЕ ВАВИЛОВА-ЧЕРЕНКОВА ПРИ ПРОЛЕТЕ ЗАРЯДА ВБЛИЗИ ДИЭЛЕКТРИЧЕСКОЙ ПРИЗМЫ

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Аннотация. *Работа посвящена изучению характеристик излучения Вавилова-Черенкова (ИВЧ) при прямолинейном равномерном движении электрического зарядка в вакууме, вблизи диэлектрической мишени с различными параметрами. Проведено моделирование для излучения Вавилова-Черенкова в оптическом диапазоне длин волн, показано, что ИВЧ может использоваться для оперативной диагностики параметров ускоренных пучков.*

Introduction. The effect of Vavilov-Cherenkov radiation refers to a special class of interaction in which the radiation of electromagnetic waves occurs at constant particle motion in a medium at a speed exceeding the light speed in a medium with a refractive index $n > 1$. In this case, a charge moving in a medium at a constant speed radiates electromagnetic waves with an angular distribution and a continuous spectrum.

The condition for the emergence of the Vavilov-Cherenkov radiation:

$$\mathrm{Cos}(\theta) \cdot \beta \cdot n = 1, \tag{1}$$

where θ is the angle between the direction of radiation and the direction of motion of the electric charge, which is performed only in a medium with a refractive index $n > \beta^{-1} > 1$. The radiation pattern arises from the condition (1). The Vavilov-Cherenkov radiation (VCR) spreads in a conical sector. Its axis is located along the velocity vector of the charge. In 1947, Frank and Ginzburg investigated the radiation, which arises from a charge constantly moving along the axis of a cylindrical channel. It was made in a medium with a dielectric constant ε_1 and filled with a substance with ε_2 [1]. This issue is important because the losses on the VCR are relatively small in case the charge moves in the medium. In this case the main losses are the ionization losses near the trajectory. There are no ionization losses and the VCR remains when flying in channels, slits or near.

VCR is useful in particle physics. It can be used to measure the characteristics of particles, which pass through the dielectric. Detectors based on this effect are used in laser plasma laboratories, tokamaks, particle accelerators such as the Large Hadron Collider. In this case, the particle passes through the medium and loses energy to dissipate. Sometimes dispersion can be neglected, but there are options when it is not. In this regard, non-disturbing methods of particle diagnostics are necessary.

It was considered that VCR which arises from the passage of the particles close to the dielectric, and not when it is crossed, is negligible. The results of the simulation conducted by the scientists of Tomsk Polytechnic University, and the direct experiment conducted at the american accelerator at Cornell University, refuted this opinion [2]. The results of the experiment showed that the generated VCR has no significant effect on the bunch parameters. The results are well described by the existing model.

Simulation. In the article [3] the method of polarization currents was used to solve the problem of VCR in the motion of the charge near the dielectric prism of final size, which has an arbitrary dielectric constant. The drawing of generation of polarization radiation from a charged particle, moving constantly near a dielectric wedge, is shown in Fig. 1.

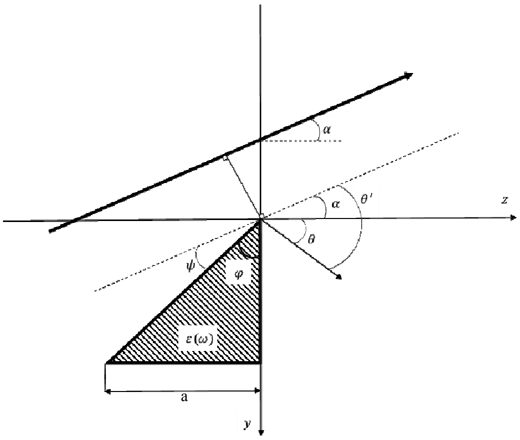

Fig. 1. Generation of radiation from a charged particle moving constantly near a dielectric wedge

The spectral-angular distribution of polarization radiation in the positive direction of the z axis is determined by the equation (2). This expression of the spectral-angular density takes into account both diffraction radiation and VCR.

$$
\begin{aligned}
\frac{d^2W}{d\omega d\Omega} &= \frac{e^2\beta^2}{4\pi^2 c}\frac{\cos^2(\theta'-\alpha)}{|P|^2}\left|\frac{\varepsilon-1}{\varepsilon}\right|^2\left|1-\frac{P\,\mathrm{Exp}\left[i\frac{\omega}{\beta c}\Sigma a\,\mathrm{Cot}[\phi]\right]+\Sigma\,\mathrm{Cot}[\phi]\mathrm{Exp}\left[-i\frac{\omega}{\beta c}aP\right]}{P+\Sigma\mathrm{Cot}[\phi]}\right| \\
&* \left\{\left|\frac{\varepsilon}{\varepsilon\cos(\theta'-\alpha)+\sqrt{\varepsilon-\sin^2(\theta'-\alpha)}}\right|^2\left|\cos\alpha\left(\gamma^{-1}\sin(\theta'-\alpha)-iK\cos\varphi\sqrt{\varepsilon-\sin^2(\theta'-\alpha)}\right)\right.\right. \\
&\left.+\sin\alpha\left(iK\sin(\theta'-\alpha)+\gamma^{-1}\cos\varphi\sqrt{\varepsilon-sin^2(\theta'-\alpha)}\right)-\gamma\beta\sin(\theta'-\alpha)\sqrt{\varepsilon-\sin^2(\theta'-\alpha)}\sin^2\varphi\right|^2 \\
&+\left|\frac{\sqrt{\varepsilon}}{\cos(\theta'-\alpha)+\sqrt{\varepsilon-\sin^2(\theta'-\alpha)}}\right|^2(\gamma\sin\varphi)^2\left(\sin^2(\theta'-\alpha)+\left|\sqrt{\varepsilon-\sin^2(\theta'-\alpha)}\right)\right| \\
&\left. * \left[1-\beta^2\cos^2(\theta'-\alpha)+2\beta\gamma^{-2}\sin\alpha\sin(\theta'-\alpha)\cos\varphi-\gamma^{-2}\sin^2\alpha(K^2-\gamma^{-2})\right]\right\} \\
&* \frac{\mathrm{Exp}[-2\frac{\omega}{\gamma\beta c}(h+a\,\mathrm{Cot}\,\phi)K\cos\alpha]}{K^2(1-\beta^2\cos^2(\theta'-\alpha)+\beta^2\sin^2\alpha\,[1-\sin^2(\theta'-\alpha)\sin^2\varphi]+2\beta\sin\alpha\cos\varphi\sin(\theta'-\alpha))}
\end{aligned}
\tag{2}
$$

Fig. 2 shows the angular distribution of θ for ϕ=0 for the parameters from the articles [3, 4]. Using the formula for the spectral-angular distribution, we compare the resulting contour plot (Fig. 3) with the results of the article [4].

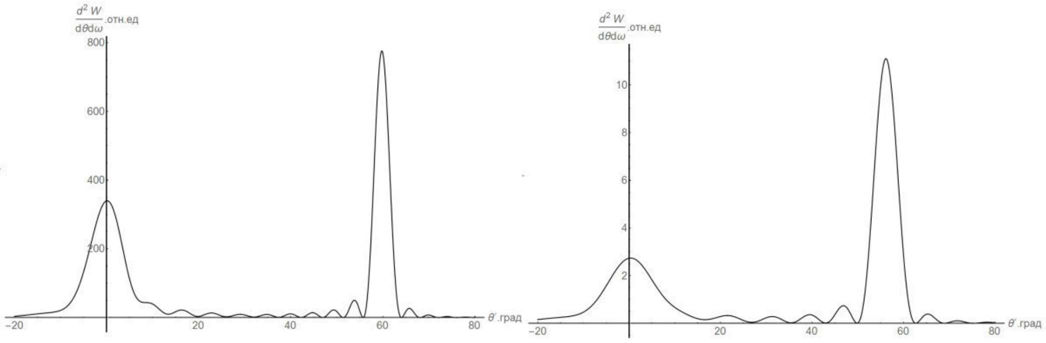

Fig. 2. Comparison of angular distribution of DR and VCR for parameters from [3]–to the left(a),[4]–to the right(b).
a) $\gamma = 22.3,\ \lambda = 0.5\ \mu m, \mathrm{a} = 50k^{-1}, \varphi = 30^{\mathrm{o}}, \varepsilon = 4$, *b)* $\gamma = 12,\ \lambda = 4\ mm,\ \mathrm{a} = 45\ mm, \varphi = 60^{\mathrm{o}}, \varepsilon = 2.2$

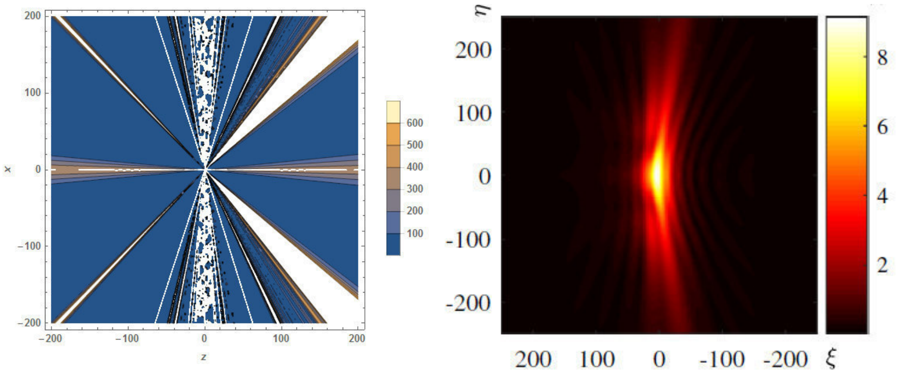

Fig. 3. Comparison of contour distribution of DR and VCR for the parameters of [4] by the formula (2) for the farzone– to the left (a), the result of [4] for the near zone– to the right (b).
$\gamma = 22.3,\ \lambda = 0.5\ \mu m, \mathrm{a} = 50k^{-1}, \varphi = 30^{\mathrm{o}}, \varepsilon = 4$

Conclusion. In this article modeling of the Vavilov-Cherenkov radiation generation process in the optical wavelength range is carried out. Basing on the calculations results, we can conclude that the formulae (2) give a realistic picture of the radiation. In Fig. 2 it can be observed that the VCR has a higher intensity than the diffraction radiation. VCR can be used for bunch diagnostics because it is generated at large angles with respect to the trajectory in favorable background conditions. There is a difference in VCR characteristics in Fig. 3 due to the fact that the model [4] describes VCR in the near zone, while the model [3] – in the far zone.

REFERENCES

1. Ginzburg V. L., Frank I. M. (1947), DAN USSR 56, 699
2. Kieffer R.,Bartnik L., Bergamaschi M., Bleko V. V., Billing M., Bobb L., Conway J., Forster M., Karataev P., Konkov A. S., Jones R. O., Lefevre T., Markova J. S., Mazzoni S., Padilla Fuentes Y., Potylitsyn A. P., Shanks J., and Wang S. (2018, August). Direct Observation of Incoherent Cherenkov Diffraction Radiation in the Visible Range Phys. Rev. Lett. 121
3. Shevelev M. V., Konkov A. S. (2014). Features of generation of Vavilov-Cherenkov radiation during the passage of a charged particle near a dielectric target. Tomsk Polytechnic University, volume 145, issue. 4, pp. 579-590.
4. Tyukhtin A. V., Vorobev V. V., Galyamin. Radiation of a charge moving along the boundary of dielectric prism. Saint-Petersburg State University.