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Optical diffraction radiation for position monitoring of charged particle beams

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ABSTRACT

In the framework of the future linear collider collaboration (CLIC, ILC), non-intercepting beam monitoring instruments are under development for very low emittance and high charge density beams. Optical diffraction radiation (ODR) was studied and developed during the last years focussing on beam size measurements. We propose in the paper to consider the use of diffraction radiation for ultra relativistic beams as position monitors with applications for the centering of scrapers, collimators and targets with high resolution. We present the experimental results obtained using small aperture slits on the ATF2 extraction beam line at KEK and on the Cornell Electron Storage Ring with 1.2 GeV and 2.1 GeV electrons respectively.

1. Introduction

Optical transition radiation (OTR) refers to the electromagnetic field emitted by a charged particle when it crosses the boundary between two media of different dielectric constants [1]. Optical diffraction radiation (ODR) is a non-interceptive alternative to OTR, where the particle passes through a narrow aperture, i.e a slit or a hole (see [2] and references therein). The particle Coulomb field generates polarisation currents on the slit edges that in turn give rise to radiation, see Fig. 1.

During the last 20 years, beam size monitors have been developed based on the measurement of the ODR angular distribution [3,4]. In this context we are performing experimental studies both on the ATF2 electron beam line at KEK [6], and on the Cornell Electron Storage Ring (CESR) [5]. In this paper we discuss the possibility to use diffraction radiation as a way to measure with micron scale resolution beam position in slits or collimators as an alternative to conventional electrostatic beam position monitors [8]. We present then a set of measurements, performed on the test facilities mentioned previously, showing beam position measurements in small slits using direct imaging of the ODR spatial distribution.

2. Beam position measurement using ODR

The intensity of the ODR light emitted by the edges of a slit depends on the observation wavelength, on the beam energy and on the relative position of the beam with respect to the slit [2]. The best sensitivity for ODR based position measurements is obtained when the slit aperture a is of the order of magnitude of the effective electromagnetic field radius of the charged particle defined by:

$$a \simeq \frac{\gamma\lambda}{2\pi}, \quad \gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \qquad (1)$$

where λ is the observation wavelength and γ the particle relativistic factor.

The graph, presented on Fig. 2, shows the single electron effective field radius as a function of wavelength both for the beam energy available at ATF2 (red), and CESR (blue). The horizontal lines correspond to the slit sizes we tested. The line crossing points would indicate the most favourable optical wavelength to be chosen in each configuration. This would suggest to work at 800 nm with a 0.5 mm slit on CESR and with 400 nm and 200 nm wavelength on ATF2 with slit apertures of 160 μm and 80 μm respectively. A typical vertically polarised single electron ODR spatial

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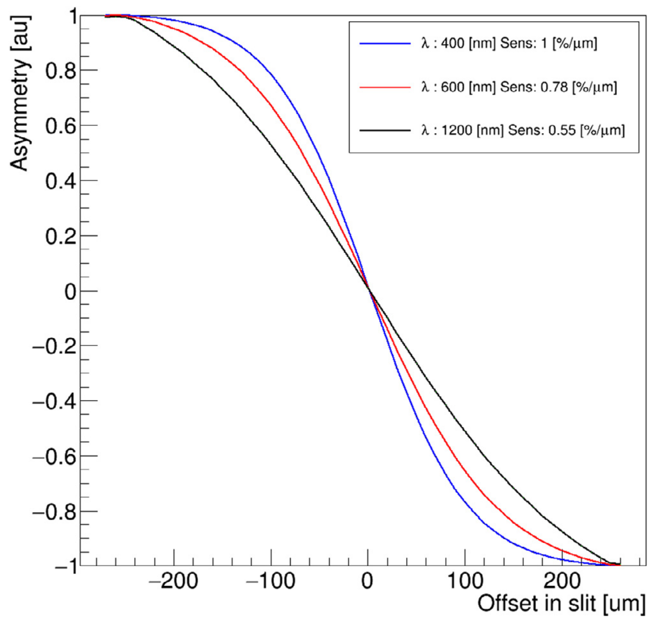

Fig. 1. Schematic view of the ODR light production mechanism on the aluminium target surface. Dark blue: electron beam. Light blue: ODR photons. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

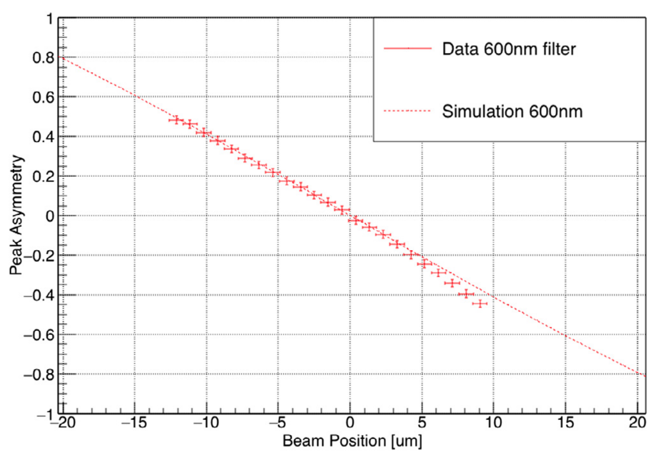

Fig. 2. Wavelength versus ODR effective field radius. Used slit sizes are reported as horizontal lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

distribution presented on Fig. 3 was simulated using the field described in [7].

Since the ODR effective field radius is of the same order of magnitude as the slit aperture, an electron bunch passing off-center will generate more light on one side of the slit than the other. The profiles presented on Fig. 4 are the projection along the vertical axis of the ODR field as shown on Fig. 3 for different beam offsets. The asymmetry between the two peak amplitudes emitted by the top and the bottom edges of the slit can be used to measure the beam position with respect to the slit center. The profiles visible in Fig. 4 are fitted to extract the peak amplitudes A_{top} and A_{bottom}, and the asymmetry is evaluated using the formula (2).

$$Asym = \frac{A_{top} - A_{bottom}}{A_{top} + A_{bottom}} \quad (2)$$

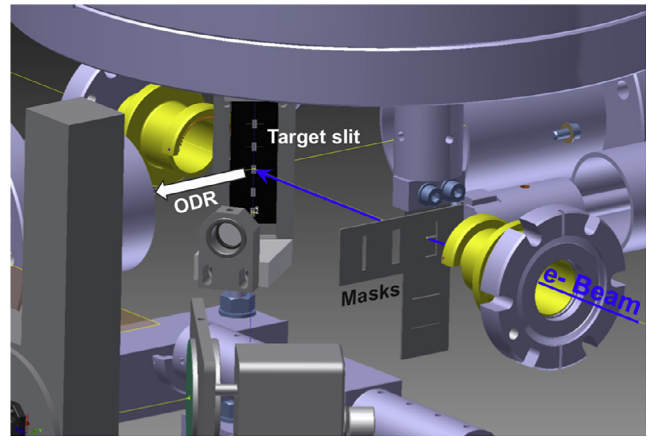

Fig. 3. Simulated ODR spatial distribution on the surface of the 0.5 mm slit target at 400 nm wavelength. The 2.1 GeV electron is passing into the slit center.

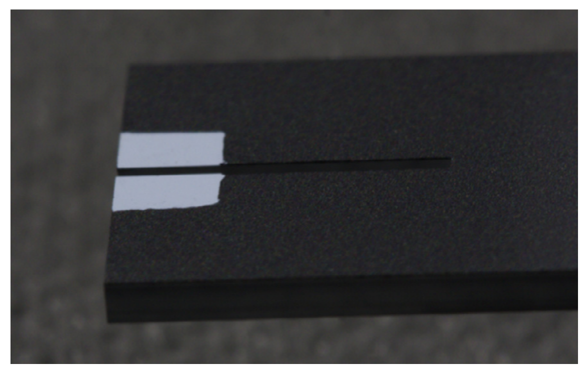

Fig. 4. Vertical projections of the ODR spatial distribution simulated for different beam offsets with respect to the slit center.

For a given beam energy and slit aperture, the choice of the observation wavelength is crucial and the asymmetry curve will change significantly depending on the wavelength in use. As shown on Fig. 5 assuming 2.1 GeV electrons, the response of the ODR BPM for a 1.2 μm wavelength is quite linear almost over the full slit aperture (0.5 mm), and provide a sensitivity of 0.55% asym-

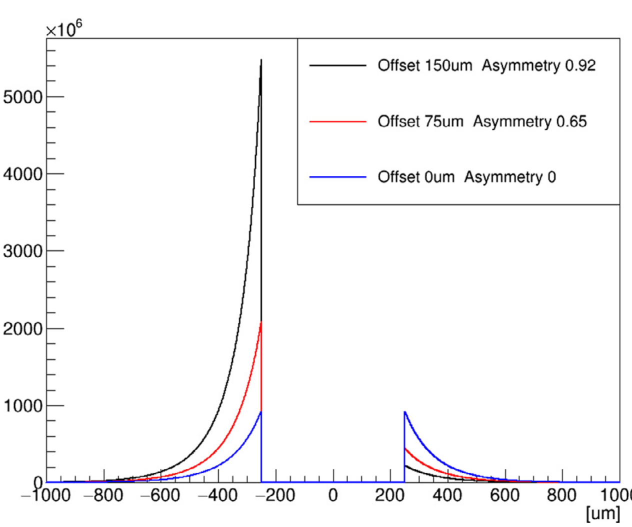

Fig. 5. Simulations of the ODR vertical profile peak asymmetry for a 2.1 GeV electron beam scanned into a 0.5 mm slit (three wavelengths).

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