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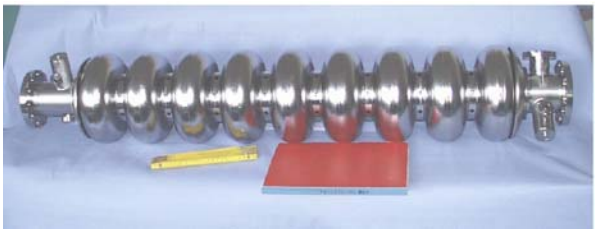

Non-Intercepting Electron Beam Transverse Diagnostics with Optical Diffraction Radiation at the DESY FLASH Facility

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Abstract

Since knowledge of the characteristics of the accelerated beams is of a great importance for the successful development of the next generation light sources and linear colliders, characterization of the transverse phase space for high charge density and high energy electron beams is a fundamental requirement in many particle accelerator facilities. The development of suitable beam diagnostics, non-invasive and non-intercepting, is necessary to measure the properties of such beams. Optical Diffraction Radiation (ODR) is considered as one of the most promising candidates, as shown by the interest of many laboratories all around the world [1],[2]. An experiment based on the detection of ODR has been set up at DESY FLASH Facility to measure the electron beam transverse parameters. The radiation is emitted by a 700 MeV electron beam passing through a 0.5 mm or 1 mm slit. The slit opening is produced by chemical etching on a screen made of aluminum deposited on a silicon substrate. Radiation is then detected by a high sensitivity CCD camera. The status of the experiment and preliminary results are reported.

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INTRODUCTION

Linear colliders and short wavelength Free Electron Lasers (FEL) require ultra-high brilliant electron beams of so much power density that no intercepting device can sustain it. Therefore, non-intercepting diagnostics is strongly desired.

Diffraction Radiation (DR) is emitted by a charged particle beam going through a slit in a metallic foil due to the interaction of the electromagnetic field (EM) of the charge with the boundary. The DR angular distribution is produced by the interference of radiation from both edges of the slit. The visibility of the interference fringes is correlated to the beam size[3]. The effect is also affected, in a slightly different way, by the angular divergence of the beam paving the way to an emittance measurement.

DR THEORY

DR is produced when a charged particle goes through a slit or passes by the edge of a metallic screen, due to the interaction between the EM field of the traveling charge and the target surface[4]. The intensity of the radiation increases linearly with the number of charges and is proportional to $e^{-\frac{2\pi a}{\gamma\lambda}}$, where a is the slit aperture, γ the Lorentz factor and λ the emitted wavelength. The factor $\frac{\gamma\lambda}{2\pi}$, called as DR impact parameter, is the natural size of the radial extension of the EM field, thus when $a \cong \frac{\gamma\lambda}{2\pi}$ DR is emitted.

Since the beam goes through the slit, DR is a non-intercepting diagnostics and therefore excellent to be used parasitically without spoiling the electron beam.

The angular distribution of the DR is mainly affected by beam parameters in the plane orthogonal to the slit aperture: when the transverse beam size is increased, both the peak intensity and the central minimum increase, resulting in the reduction of their ratio. The same effect is also shown when the slit is scanned vertically providing a method to determine the center of the slit by minimizing the minimum of the total intensity.

EXPERIMENTAL APPARATUS

Our experiment is carried out at FLASH, Free electron LASer in Hamburg, at DESY. FLASH is an excellent facility for this experiment, since it can drive long bunch trains, up to 800 bunches per macropulse allowing a high charge operation, and it has a good long term stability, a small transverse emittance (∼ 2 mm mrad), and a high electron beam energy (up to 1 GeV in the near future).

Our experimental set-up is placed in the by-pass beam line (Fig. 1) very far (about 40 m) from the dipole magnets in order to minimize the contribution of synchrotron light.

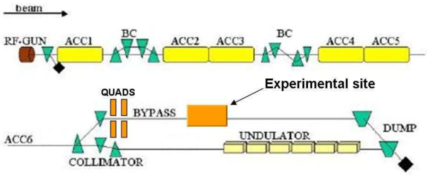

Figure 1: FLASH layout and experimental site.

The experimental apparatus has an aluminized silicon ni-

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tride screen (DR screen) mounted at 45^o angle with respect to the beam direction. The DR screen is constructed by lithographic technique starting from a silicon nitride wafer and opening two slits, one of 0.5 mm and the other of 1 mm aperture, by means of chemical etching. The slits are spaced by 2 cm and the space between the slits is used as a standard OTR screen. The main advantage of the silicon nitride with respect to SiO_2[5] is a much less etching rate which preserves the silicon substrate from damages and makes the surface much more uniform. An aluminum layer is deposited by sputtering on the target to enhance the reflectivity.

Radiation from the target is reflected by a mirror and sent through an optical system to the camera. Two lenses, one to image the beam, the other one to produce the DR angular distribution, can be selected. They have different focal length in order to have the focus on the same plane. Two interferential filters, at 800 nm and 450 nm, and a polarizer may be inserted on the optical axis. Due to the very low radiation intensity, a high sensitivity CCD camera (Hamamatsu Model C4742-98-LGLAG2) is used. The optical system layout is shown in Fig. 2.

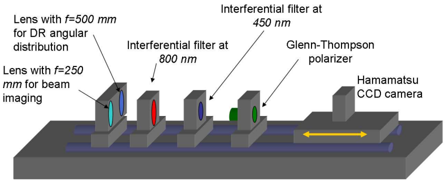
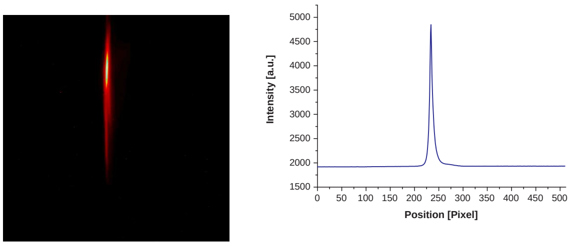


Figure 2: Sketch of the optical system.

PRELIMINARY RESULTS

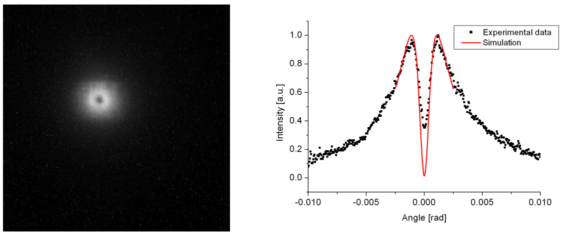
In this section we report the preliminary results obtained with a 680 MeV electron beam energy going through a 0.5 mm slit. During measurements reported in this paper, FLASH was operated with up to 25 electron bunches (0.7 nC per bunch) per macropulse with 1 MHz bunch spacing. The macropulse repetition rate was 5 Hz.

The image of the beam and its intensity projection are shown in Fig. 3a and Fig. 3b, respectively. The retrieved rms size is about 80 μm. Since Optical Transition Radiation (OTR) is theoretically and experimentally well understood, we first verified our experimental setup by acquiring the OTR angular distribution (Fig. 4) and deriving from that the beam energy. The uncertainty on the beam energy, about 10%, is compatible with the uncertainty on both the focal length and the position of the focal plane. The disagreement on the minimum depth between the measured and the simulated curves might be attributed to a residual background and not to the angular divergence of the beam.



(a) Beam image (b) Beam projection

Figure 3: Image of the beam on the OTR screen (a) and its projection (b).



(a) OTR angular distribution and background (b) OTR projection

Figure 4: OTR angular distribution: a) image with background, b) measured and simulated projection.

Critical Issues

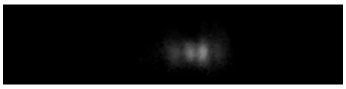
The main limitation during the measurements was given by the synchrotron radiation background coming not only from the dipole, but also from the quadrupole magnets upstream of our experiment and from multiple reflections in the vacuum pipe. As a consequence, the background is the image of a source apparently near (few meters) to the target itself, clarifying its peculiar shape and preventing from the knowledge of a theoretical behavior which would be easily subtracted.

The background image is every time acquired by moving the beam out of the screen by means of steering magnets upstream of the target. However, since the steered beam hits the vacuum pipe, this procedure gives rise to a large amount of X-rays. In order to increase the signal-to-noise ratio, a large number of images has been recorded. The images are then off-line processed in order to first eliminate X-rays and then subtract the background from the signal.

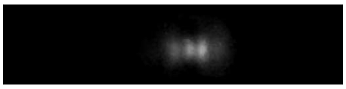
ODR Evidences

To take a snapshot of a clear signature of ODR angular distribution, several images of both signal and background have been acquired scanning vertically the slit aperture.

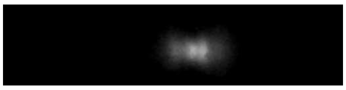
Figure 5 shows the vertically polarized angular distribution for three values of displacement of the beam with respect to the center of the slit. The corresponding measured angular distribution projection is shown in Fig. 6a). The black squares curve corresponds to the beam in the center (ODR). As we move far from the center, both the minimum and the maximum intensities increase and the visibility of



(a) 0 μm



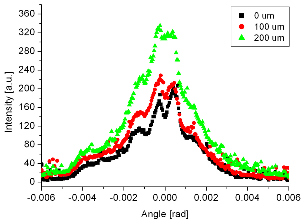
(b) 100 μm



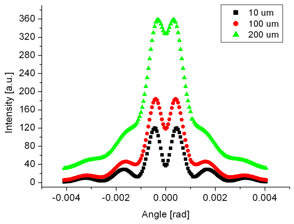
(c) 200 μm

Figure 5: Vertically polarized angular distribution for different position of the beam within the slit.

the interference fringes becomes less pronounced, as also shown by the simulation (Fig. 6b). The noisy and asymmetric curves are due to a residual background contribution.



(a) Experimental data



(b) Simulation

Figure 6: Angular distributions for different positions of the beam with respect to the center of the slit. Both the polarizer and the 800 nm filter are inserted.

As expected from theory, Fig. 7 shows the minimum intensity corresponding to the center of the slit. In optimum conditions and with a better background subtraction, this result might be used as independent measure to determine the beam size[6].

From the previous scan we determined the center of the slit and we performed a dedicated measurement of ODR signal and background to optimize the subtraction procedure. For this measurement, the projection of the ODR angular distribution image is shown in Fig. 8 (black squares). A simulation which takes into account a Gaussian distributed beam with $\sigma = 70$ μm and $\sigma' = 30$ μrad, shows a good qualitative agreement with the measured ODR projection (Fig. 8, red line).

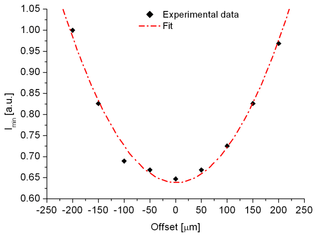


Figure 7: Measured dependencies of ODR minimum intensity as function of the displacement of the beam within the slit.

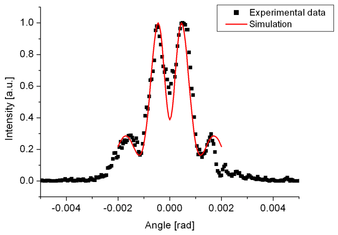


Figure 8: ODR angular distribution: 25 bunches, 0.7 nC per bunch, 0.5 mm slit. Polarizer and 800 nm filter are inserted.

CONCLUSIONS

The background is a severe limitation for a detailed and quantitative reconstruction of the beam parameters from the ODR angular distribution. To reduce its influence we have foreseen to mount a new thin shield in front of the target and replace the holder with one which is machined such that reflections are strongly suppressed.

In our data analysis we have put much effort on the image processing to clean images from X-rays and to subtract the synchrotron radiation background. This allowed us to prove a good qualitative agreement between the experimental data and the simulations.

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