OPTICAL DIFFRACTION RADIATION INTERFERENCE

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1 Introduction

Fourth generation light sources, e.g. Free-Electron Lasers (FEL), and future linac colliders demand high brightness, high repetition rate electron beams. The control and measurement of beam parameters, in particular transverse emittance, along the accelerator is one of the fundamental diagnostic required for such facilities. Conventional diagnostic methods, based on the interaction of the electron beam with intercepting measurement devices, might not be suitable due to the high charge density, high energy characteristic of such beams. Diffraction radiation (DR) diagnostic is based on the observation of the DR angular distribution emitted by an electron beam passing through an aperture in a metallic foil. DR is produced by the interaction of the electromagnetic field of an electron beam with the screen surface. Since the beam goes through the aperture, DR-based diagnostics is suitable for measuring the properties of such beams in a non-intercepting, non-perturbing way.

2 ODRI experiment

The aim of the experiment, set up at FLASH (DESY), is studying the angular distribution of incoherent optical DR (ODR) which gives information on both transverse beam size and angular divergence, to allow a single shot emittance measurement provided the beam has its waist on the DR screen. Some limitations of ODR diagnostic [1)] can be overcome by mounting a shielding mask normally to the beam and in front of the DR screen. Since the two slits have different apertures (1 mm the mask and 0.5 mm the DR screen), the amplitudes of the two sources are different both in intensity and in angular distribution, resulting in an advantageous interference effect. We call it ODRI, i.e. Optical Diffraction Radiation Interference, produced by the interference between forward ODR emitted on the shielding mask and backward ODR from the DR target [2)]. The main benefits are given by the reduction of synchrotron radiation background, the increase of the sensitivity of the angular distribution on the beam size, and the possibility to distinguish effects caused by beam size and offset [3)] within the slit.

3 Achievements in 2012

The planning for the ODRI experiment scheduled in February 2012 during accelerator studies concerned the following two items:

- the measurement of the ODRI angular distribution from both round beams and beams with different aspect ratio, i.e. flat beam typical for colliders, which means different angular divergences;
- the achievement of a totally non intercepting quadrupole scan, therefore the first ever measurement of the normalized transverse emittance by means of ODRI angular distribution.

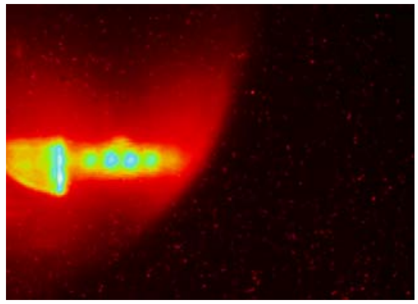

Figure 1: *ODRI angular distribution produced by 1 bunch of 200 pC at 800 nm. The large background is visible all around the signal.*

During the first 12-hour shift, the beam has been successfully transported up to the bypass, into the ODRI experimental station. achieving transverse beam dimension below 50 μm RMS in both planes. This starting point was needed to check the alignment of the optical system with the Optical Transition Radiation (OTR). All these tests have been performed at 1 Hz, to avoid any interruption caused by the radioprotection system.

The beginning of the second 12-hour shift has been characterized by a large signal background, being an indication of coherent emission as result of micro-bunching instability enhanced by the bypass dispersive line [5].

Indeed, beyond the huge background (1), we observed saturation of the OTR beam image even at very low charge, *i.e.* less than 100 pC. The main contribution seemed due to coherent synchrotron radiation coming from upstream with respect to the DR screen.

At the beginning of the third 12-hours shift, we decreased the laser iris in order to preserve the charge density at the cathode, according to the last measurements in January 2011. After that we found a much smoother transport up to the ODRI station, we did not have any strong evidence of coherent emission anymore. This configuration allowed us to tune the beam in order to have small spot size at the DR target. The minimum spot size measured was 50 μm in both directions. We tuned better also the light optics system looking at a clean ODRI angular distribution image. The goal of the shift was the quadrupole scan emittance measurement performed with both OTR beam imaging and ODRI angular distribution measurement.

The emittance has been measured at two observation wavelengths, 800 nm and 500 nm, by means of the quadrupole scan technique, using the last quadrupole before the DR target. Two quadrupole scans have been performed to compare and validate our result. We report here only the the case at 800 nm observation wavelength.

The first quadrupole scan was intercepting, by OTR imaging of a single electron bunch, the second one, fully non-intercepting, looking at the ODRI angular distribution, produced by a 2s integration of 20 bunches traveling through the slits at 10 Hz. The higher number of bunches was needed to increase the signal to noise ratio.

From the standard quadrupole scan we measured a normalized vertical emittance as low as 3.6 (0.4) mm mrad, in very good agreement with the normalized vertical emittance retrieved through the measured ODRI angular distributions, *i.e.* 3.7 (0.8) mm mrad. Data and fit are shown in 2 (black, squares and solid line, for ODRI angular distribution and red, circles and solid line, from OTR imaging).

The forward tracking of the beam optical function (Twiss parameters) allowed to estimate both vertical RMS beam size and divergence at the ODRI target, *i.e.* $\sigma_y = 73$ μm and $\sigma_y^{'} = 31$ μrad. These values are in very good agreement with those retrieved from the fit of the measured ODRI angular distribution. An is shown in Fig.3.

Due to a residual coherent emission, we did not succeed to try the transport of the flat beam. Therefore, we collected some statistics and ODRI angular distribution data with round beam at different wavelengths (between 500 nm and 800 nm) and for both polarization, *i.e.* vertical and

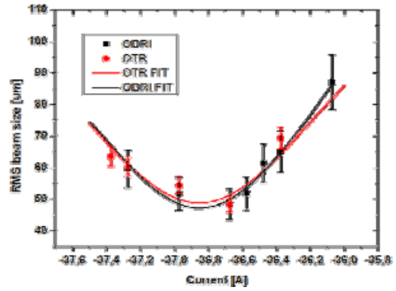

Figure 2: *RMS vertical beam size measured, at the ODRI station, by both OTR imaging (red circles) and ODRI angular distribution (black squares), as function of the current of the upstream quadrupole. The red and black solid curves result from the chi-square fit. The retrieved normalized vertical emittance from the intercepting, OTR-based, measurement is 3.6 (0.4) mm mrad, in very good agreement with the one obtained through the fully non-invasive ODRI-based measurement, i.e. 3.7 (0.8).*

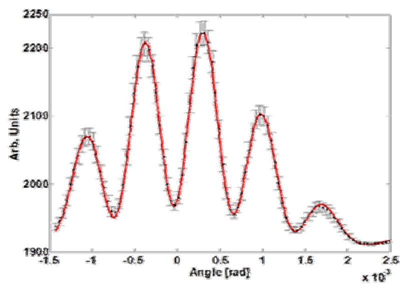

Figure 3: *Example of a profile of the measured ODRI angular distribution. Superimposed the fit calculated by Minuit. The cut on the left of the angular distribution is due to some stray light that falls into the CCD camera.*

horizontal.

In Summer 2012, the bypass line has been dismounted to allow the upgrade to FLASH2. The ODRI diagnostics station has been requested to be mounted at FLASH2 on the main line after the variable gap undulator, where optimized electron beam transport is foreseen.

In addition to the operation of ODRI as standard diagnostics, further experiments are foreseen to study the contribution and the effects of coherent emission due to microbunching within the electron beam. These tasks will concern the activity in the following 3-years project, named as ODRI2D, starting in 2013.

4 Publications during the 3-years project

- M. Castellano, E. Chiadroni, A. Cianchi, "Phase Control Effects in Optical Diffraction Radiation from a Slit", Nucl. Instr. and Methods in Physics Research A **614**, 163 - 168 (2010).
- A. Cianchi *et al.*, "Nonintercepting electron beam size monitor using optical diffraction radiation interference", Phys. Rev. Special Topics - Accel. and Beams **14**, Issue 10, 102803 (2011).
- E. Chiadroni, M. Castellano, A. Cianchi, K. Honkavaara, G. Kube, "Effects of transverse electron beam size on transition radiation angular distribution", Nucl. Instr. and Methods in Physics Research A **673**, 56 - 63 (2012).
- V. Shpakov, S. Dabagov, M. Castellano, A. Cianchi, K. Honkavaara, G. Kube, E. Chiadroni,

"Far- and near-field approximation for diffraction radiation", Nucl. Instr. and Methods in Physics Research B (accepted for publication), 2013.

5 Acknowledgment

Authors wish to thank colleagues collaborating from participant institutions: L. Catani, A. Cianchi (INFN Roma 2-Tor Vergata) and V. Balandin, N. Golubeva, K. Honkavaara, G. Kube (DESY). In addition we would like to acknowledge S. Dabagov and V. Shpakov (collaborating PhD student from Moscow University) for important theoretical contributions.

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1. E. Chiadroni *et al.*, Nucl. Instr. and Meth. in Phys. Res. B **266**, 37893796 (2008).

2. E. Chiadroni, M. Castellano, A. Cianchi, K. Honkavaara, G. Kube, TUOA02, in: Proc. of DIPAC 2009, Basel, Switzerland.

3. A. Cianchi *et al.*, "Nonintercepting electron beam size monitor using optical diffraction radiation interference", Phys. Rev. Special Topics - Accel. and Beams **14**, Issue 10, 102803 (2011).

4. A. Cianchi *et al.*, Proc. of the RREPS Conference, London, UK (2011).

5. E. Chiadroni, M. Castellano, A. Cianchi, K. Honkavaara, G. Kube, "Effects of transverse electron beam size on transition radiation angular distribution", Nucl. Instr. and Meth. in Phys. Res. A 673, 56 - 63 (2012).