DEVELOPMENT OF A VERSATILE OTR-ODR STATION FOR FUTURE LINEAR COLLIDERS.

R. Kieffer, T. Lefevre, S. Mazzoni, CERN, Geneva, Switzerland
L. Bobb, Diamond Light Source, Oxfordshire, UK
M. Bergamaschi, P. Karataev, T. Aumeyr, JAI, Egham, Royal Holloway, Univ. of London, Surrey, UK
M. Billing, J. Conway, J. Shanks, Cornell University, CLASSE, Ithaca, NY, USA
N. Terunuma, KEK, Tsukuba, Japan

Abstract

In order to study the feasibility of Optical Transition (OTR) and Diffraction (ODR) Radiation based profile measurement for the future electron-positron linear colliders (ILC, CLIC) a new dedicated instrument is under development at CERN to be installed in the Accelerator Test Facility 2 (ATF2) at KEK in fall 2015. To optimize sensitivity to micron and sub-micron beam sizes, we plan to observe ODR/OTR in the visible-UV wavelength range, down to approximately 150 nm. In this paper, we will present the status of the project with a focus on the target development which is one of the most critical aspects of the design.

INTRODUCTION

OTR beam imaging systems are widely used to measure the transverse properties of a particle beam. Recently, sub-micron beam size measurements have been reported on the ATF2 extraction beam line by measuring the visibility of the OTR point spread function [1–3]. However, as OTR occurs where a particle beam crosses a boundary between two different dielectric media, e.g. a Si target, the measurement is strongly invasive. An OTR target will withstand a single bunch but will get quickly damaged when using longer bunch trains as foreseen in linear colliders. A non-interceptive alternative for high power beams would be to replace the solid target by a slit, which will emit ODR. The Coulomb field induced by the beam generates polarisation currents on the slit edges that in turn give rise to radiation [4]. Similarly to OTR, Diffraction radiation will be emitted both in the backward (BDR) and forward (FDR) direction. Beam size information is retrieved from the far-field angular distribution of ODR. Experiments using ODR were performed in 2004 [5] measuring beam sizes as small as 14 microns. Since then ODR has been developed further [6] to provide online transverse beam size monitoring. Further improvements in resolution can be achieved by a careful optical design as well as the observation of DR at smaller wavelength down to 150 nm. In 2010, an experimental test program [7] was initiated aiming at developing the DR slit technology and possibly demonstrating resolution down to few microns.
In this paper, a combined Optical Transition Radiation (OTR) and Diffraction Radiation (ODR) monitor is being proposed to measure the ultra-small emittance of beams generated in damping rings. The latest results on slit development tested at Cornell are also discussed.

THE ODR/OTR STATION FOR ATF2

The Accelerator Test Facility 2 (ATF2) at KEK extracts a 1.28 GeV electron beam from the low-emittance damping ring of ATF, which can be focussed to a sub-micron vertical beam size [8], making it an ideal test facility for high resolution beam size studies. The first phase of the experiment will be dedicated to the OTR Point Spread Function (PSF) and ODR/OTR angular measurements in the visible range. At a later time, the setup will be upgraded with a UV ODR line to further improve optical resolution.

Description of the Setup

The station, as depicted in Fig. 1, will be composed of a mirrored target and a set of two masks (horizontal, vertical) in order to shield the target from synchrotron radiation. Mask and targets can be inserted and removed one by one with micrometer precision actuators. Two UV-compatible view ports sitting at 40 and 90 degrees with respect to the beam axis will be used to extract the light from the tank.

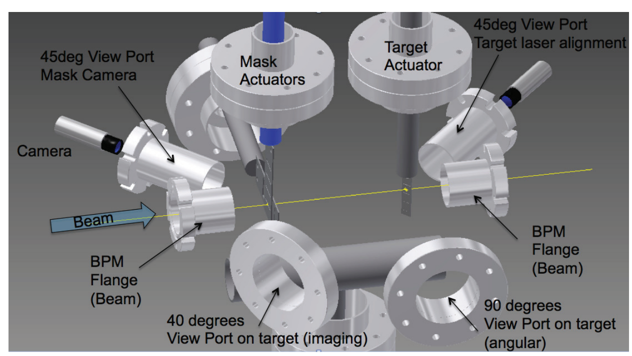

Figure 1: Sketch of the ODR-OTR station.

The OTR Optical Line

OTR will be used to measure single bunch, sub-micron beam size using the PSF visibility technique [2]. The optical line has been designed with the help of optical simulations performed with ZEMAX. [9] A two-lens system has been adopted, with a short (f = 15 mm) focal objective lens installed on the target holder producing an intermediate image that is conjugated to the camera sensor plane by means of a relay lens. This configuration allows a high magnification factor of up to M = 12 with a 4.6 mm PSF

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peak separation in the intermediate image (see Fig. 2).

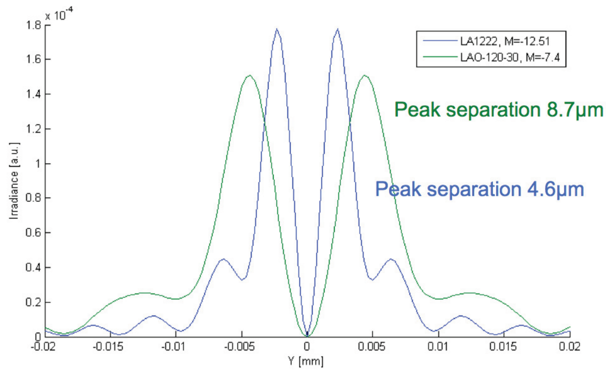

Figure 2: Zemax simulation of the expected OTR PSF for a selection of commercial lenses.

The target holder can be displaced with respect to the beam within micron step resolution (see Fig. 3). This allows the distance between source and first lens to be controlled, therefore changing the overall magnification. After band-pass and polarisation filters, the intermediate image is then imaged onto the camera (a pco edge 4.2 sCMOS) through a macro photo lens (Nikkor 40 mm f/2.8).

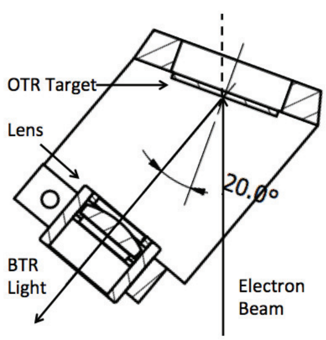

Figure 3: Sketch of the target holder in OTR position.

The ODR Setup

As mentioned before, ODR beam size measurements are derived from the reduction in visibility of the projected vertical polarisation component (PVPC) [5] of the far field angular distribution. This is achieved by placing the imaging sensor in the back focal plane of a lens. A 2 inch diameter lens of f=500 mm was chosen, allowing an approximate angular magnification of 12 μrad. The ODR target accommodates multiple slits of width d ranging from 200 to 25 μm. This ensures that DR is generated even for micrometer size beams both in the visible and UV, given that the condition $d \leq \lambda\gamma/2\pi$ holds even at $\lambda = 150$ nm for the smallest slit width. The challenging production of such a target due to the stringent requirements on surface co-planarity and slit edge roughness will be discussed in the following paragraphs.

OPTIMISATION OF THE SIGNAL TO NOISE RATIO

The design of the ODR target capitalizes on a series of ODR test runs performed at the Cornell Electron Storage Ring (CESR) test accelerator. The main noise contribution that was encountered is the synchrotron radiation (SR) emitted in bending magnets upstream the target. For ODR observation, the SR contribution can be almost equal to the ODR. Even if the SR is reduced to a much smaller amount on linear machines, such as in ATF2, it is still a source of noise that must be reduced to perform precise ODR measurements. To overcome this difficulty, two complementary approaches have been investigated and tested at CESR [6].

Synchrotron Radiation Shielding Mask

A shielding mask can be used to get rid of a part of the SR, as first suggested in [5]. In the CESR ODR experiment, a silicon carbide shielding mask was installed 15.5 mm upstream a target made of Suprasil fused silica glass with an aluminium and chromium coating to enhance specular reflection, (Fig. 4). While blocking part of the SR background, the mask is itself a new source of FDR, which will interfere with the BDR emitted from the target slit.

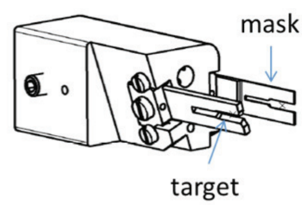

Figure 4: Isomeric view of the mask and target assembly.

Since the ODR angular distribution corresponds to the interference pattern of both FDR and BDR sources, the ratio between target and mask aperture will have a strong impact on the observed pattern. To probe this effect and evaluate the strength of this technique, a few target and mask apertures were tested on the CESR ODR setup. For the "mask:slit" ratio 4:1 shown in Fig. 5, the poor quality of the angular sides lobes is expected to be due to the interference of ODR with SR. The best signal to noise ratio was obtained using the ratio 2:1 for a 0.5 mm slit. This can be seen in Fig. 6 where the interference pattern has been fitted successfully with the theoretical model from [6] to extract the beam offset of 120 μm with respect to the slit centre, thanks to the SR shielding mask.

Reduction of Mirrored Surfaces

While imaging the target as seen in Fig. 7, we noticed that only a small part of the target is actually used in order to produce ODR light, while SR is reflected from the entire surface. To further improve the SR noise contribution, the targets have been modified to limit the highly reflective aluminium coated surfaces to small areas close to the edge that generates ODR, the light yield being proportional to the surface reflectivity.

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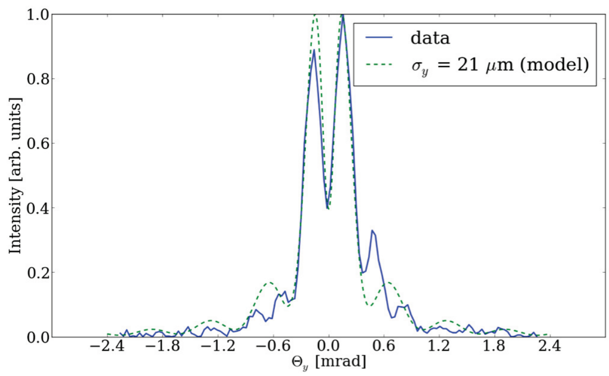

Figure 5: Angular distribution (4 mm mask : 1 mm target - Ratio: 4:1) fitted with ODR model (i. e. no interference).

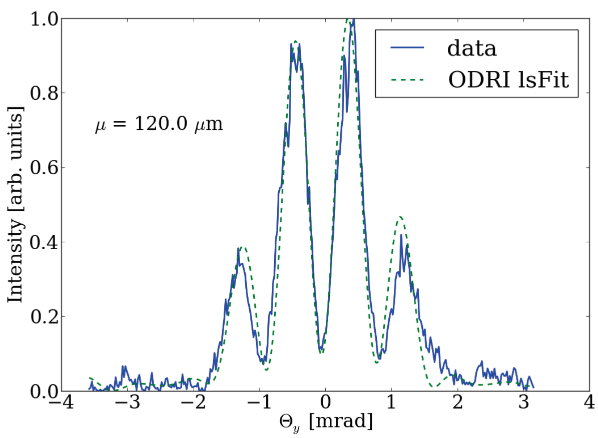

Figure 6: Angular distribution (1 mm mask : 0.5 mm target - Ratio: 2:1) fitted with ODRI model (i. e. interference between mask FDR and target BDR).

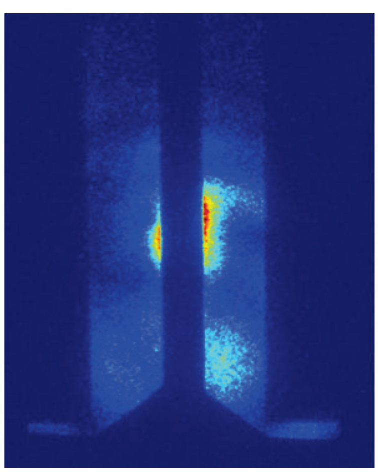

Figure 7: Imaging of the ODR target.

As the target substrate is made of glass, partial light reflection could still occur on non-coated surfaces. Multiple tests have been carried out to find the optimum way to further reduce the reflectivity around the ODR mirrors. Several samples were processed and their reflectivity spectra measured using an integrating sphere (see Fig. 8).

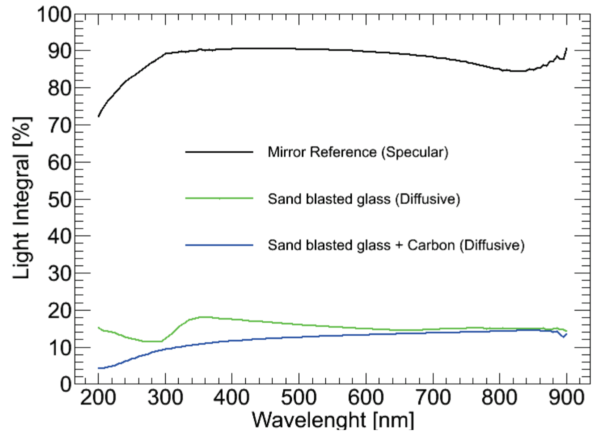

Figure 8: Reflectivity measurement, using an integrating sphere.

Micro sand blasting appears to be the most efficient technique to get a factor 6 attenuation of the reflectivity, including both specular and diffuse light. Carbon sputtering was also tried after sand-blasting. It seems to improve further the attenuation in the blue range but as it adds some complexity in the overall manufacturing process, and therefore we have not produced and tested a carbon coated target. If we scale the measured diffused power from the integrating sphere to the optical setup aperture, we obtain an attenuation factor of approximately 100 due to the fact that most of the light diffused by the sand blasted regions is not collected by the optical system.

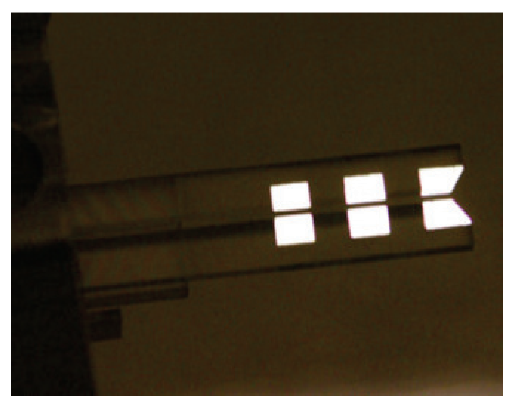

Figure 9: Reprocessed target, slit size 0.5mm, mirrors surface (2.5×4 mm^2).

A new target with three ODR mirrors (shown in Fig. 9) was tested in April 2015 at CESR. The ratio between SR and DR light was measured using angular domain images where SR and DR distributions are easily identified. Figure 10 shows their relative intensity as a function of the beam position along the slit. The SR light contribution increases as the slit is inserted further in, since the amount of SR reflected by the first two mirrored areas will contribute to the total amount of SR detected.

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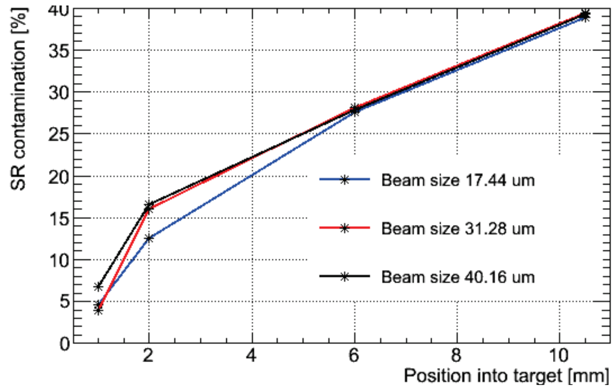

Figure 10: SR contamination in the angular domain for the three mirrors position inserting the target.

TARGET MANUFACTURING

In order to improve the sensitivity of the ODR measurement for micron-size beams, the slit must be small enough for an appreciable light yield. For the range of beam sizes and observation wavelengths considered (approximately 600 to 150 nm), slits as small as 25 μm will be required. The planarity between the two slit edges needs to be better than a tenth of the observation wavelengths ($<$ 20 nm). For the production of such a critical element, two alternative methods are being investigated. The first one makes use of the molecular adhesion between polished glass or silicon parts (see Fig. 11, top part) that are individually machined before adhesion. This technique was used successfully to produce the targets used for the CESR tests, where a co-planarity better than 20 nm was achieved.

Alternatively, chemical etching of a monocrystalline silicon wafer is being tested in the CMI-Center of MicroNano Technology at the Ecole Polytechnique Federale de Lausanne. The slit production is based on chemical anisotropic etching of the silicon (KOH etch). To ensure the best slit quality with high precision width, the photolithographic mask pattern to be chemically etched is aligned with the crystalline plane of the wafer within 0.1 degree. The process makes use of the anisotropic etching properties in order to etch through the wafer thickness from the back-side. The challenge is to obtain the desired aperture when the etching reaches through. At the time of writing, the first test sample is being produced to validate the technique. It consists of a series of slits increasing in sizes with steps of 50 μm. The planarity measurement of this sample will be the next step to validate the fabrication process.

CONCLUSION AND OUTLOOK

The OTR-ODR station to be tested on ATF2 is under development at CERN. Dedicated side experiments are conducted in order to optimise the target geometry and design. The mechanical drawings of the experimental system are now completed, and the vacuum tank is being produced by the CERN workshop. The target development is still on going. The experiment will be fully assembled and its functionalities tested at CERN in fall 2015. It is scheduled to finalise the installation on the KEK-ATF2 beamline by April 2016.

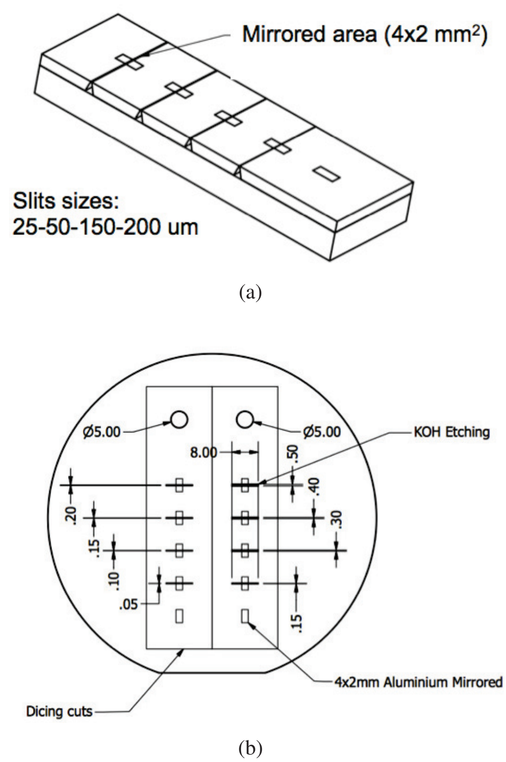

Figure 11: Molecular adhesion target (a) and chemical etching of silicon wafers (b).

REFERENCES

[1] P. Karataev et al., "First observation of the Point Spread function of optical transition radiation", Phys. Rev. Let. **107**, 174801 (2011)

[2] K. Kruchinin, et al., "Sub-micrometer transverse Beam size diagnostics using optical transition radiation", J. Phys. Conf. Ser. **517**, 012011 (2014)

[3] B. Bolzon et al., "Very High Resolution OTR Imaging System: Comparison Between Simulations and Experiment", Phys. Rev. ST Accel. Beams **18**, 082903 (2015)

[4] A. P. Potylitsyn et al., *Diffraction Radiation from Relativistic Particles*, (Springer, Berlin Heidelberg, 2010)

[5] P. Karataev, et al. "Beam-size measurement with Optical Diffraction Radiation at KEK Accelerator Test Facility", Phys. Rev. Lett. **93**, 244802 (2004)

[6] A. Cianchi, et al., "Nonintercepting electron beam size monitor using optical diffraction radiation interference", Phys. Rev. ST Accel. Beams **14**, 102803 (2011)

[7] L. Bobb, et al., "Vertical Beam Size Measurement at CESRTA Using Diffraction Radiation", in Proceedings of the 3rd International Beam Instrumentation Conference, Monterey, CA, (2014), MOPF14

[8] ATF2 Collaboration, "ATF2 Proposal", KEK report-2005-2

[9] ZEMAX user's manual, 2013.

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