Optical Diffraction Radiation at KEK-ATF2

Robert Kieffer, Thibaut Lefevre, Stefano Mazzoni, from CERN
Michele Bergamaschi, Pavel Karataev, Konstantin Kruchinin, from RHUL
Nobuhiro Terunuma, from KEK-ATF2
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Overview

• Introduction
• **OTR-ODR** Station in KEK-ATF2.
• ODR results in **Imaging**.
• ODR results in the **Angular** domain.
• Conclusions and future plans.
Small beam size challenge

• Future linear collider (ILC/CLIC) with high **luminosity** requires beams with very **small** emittances and high bunch charge.

• Non interceptive diagnostics are typically required to cope with the very high charge density.

• This is what we are developing!
OTR-ODR experiment at KEK ATF2

- The tank is installed at the virtual interaction point of ATF2 vertical beam can be focused to < 1um.

See: PS3-26 Micron-Scale electron beam size measurement using OTR, K.Kruchinin
The transverse component of the electric field from the charged particle produces surface polarization currents on the dielectric slit. Atoms on the edge of the slit are polarized, their relaxation lead to the emission of ODR photons.
Optical Diffraction Radiation

The ODR photons yield is strongly dependent on the effective electric field radius and the slit aperture \( a \) (impact parameter).

\[
a << \frac{\gamma \lambda}{2\pi} \quad \text{OTR}
\]

\[
a >> \frac{\gamma \lambda}{2\pi} \quad \text{No radiation}
\]

\[
a \approx \frac{\gamma \lambda}{2\pi} \quad \text{ODR}
\]
ODR experiment at KEK ATF2

- The target as 4 slits for ODR (56 to 200um).
- A couple of vertical and horizontal mask slits can be inserted 12.5cm upstream the target.
ODR in imaging

There is no visible beam size dependency off the pattern in imaging.
But the vertical position into the slit change the profile asymmetry => Optical Beam Position Monitor (BPM)
ODR imaging as an optical BPM

- Slit: 56um
- Beam size: 1um
- 30 shots statistics
- Position resolution: about 1um
- Steering magnet to scan the beam inside the slit.

\[
\text{Asymmetry} = \frac{P_{\text{min}} - P_{\text{max}}}{P_{\text{max}} + P_{\text{min}}}
\]

Resolution \(\sim\) 1um

Range 45um
ODR for beam size measurement

The beam size is extracted from the visibility $I_{\text{min}}/I_{\text{max}}$ of the projected vertical component of the ODR angular distribution.

An horizontal slit is used to measure a vertical beam size.

We use a polarizer to select only the vertically polarized ODR photons and 40nm BW filters to select the wavelength.

The angular distribution is obtained using a camera located at the focal plane of an optical lens (effective infinity).

Angular magnification $\theta = \arctan(d/f)$
ODR angular distribution

Both beam size and beam divergence have an effect on the visibility of the ODR pattern.

In the KEK-ATF2 case using low emittance beams the impact of the beam divergence (nrad) on the visibility is negligible compared to the beam size.
ODR target requirements

The co-planarity between the two slit sides plays a crucial role in the \textit{angular pattern symmetry}. The sum of the two slit sides contributions can be seen as an interference pattern. A co-planarity offset $b$ will introduce a phase difference:

$$\phi = \frac{b 2\pi}{\lambda}$$

\textbf{Phase shift distortion could} degrade strongly the visibility measurement. The following \textbf{co-planarity condition} must be satisfied to keep it negligible.

$$b < \left(\frac{\lambda}{20}\right)$$
ODR target development

The targets were produced from a 1400um thick silicon wafer in Lausanne at the Center of MicroNano Technology CMI EPFL.

Optical profiler image (Phase shifting interferometer)
Background source observing ODR

Synchrotron radiation SR generated by bending magnets upstream the target can be as intense as the ODR from the target!

We tested two solutions to get rid of SR contamination:
- **Removing** part of the target’s reflective area
- Using a **mask slit** upstream the target.
ODR target optimization

To improve the **Backward ODR** light yield, the silicon target surface has been **coated**.

The best reflectivity was obtained: \( \text{Al 80nm + MgF}_2 \text{ 30nm} \)

Since ODR is produced only in the vicinity of the slit sides, the rest of the target have been **sand-blasted** to reduce the reflected amount of SR (usually much more diffuse). This was tested first on Cornell CESR ring.
ODR Angular Distribution in ATF2
Filter: 450nm Slit: 105um Mask: 202um Electron beam @ 1.3GeV, 1.2nC
The visibility of ODR angular profile can be calibrated using simulation to extract the beam size. Simulation of all ATF2 Mask and Slit combinations are on-going.
ODR Light Intensity Mask size comparison

With 12.5cm distance between Mask-Target and 1.3GeV 
ODR Interference is constructive and increases integrated image intensity.
**Conclusions for ODR beam diagnostics**

**Advantages:**
- ODR is a non invasive technique:
  - Almost no particle/target material scattering.
  - Minimal wake fields effects.
- Can measure beam size and beam position (within few um resolution).
- Can be used for beam trains with very high charge ($>>10^6$ nC/cm$^2$).
- ODR target using reflective/diffusive areas and slit masks are necessary to *reduce the SR contribution efficiently*.

**Drawbacks:**
- ODR contrarily to OTR only allow to obtain a beam size measurement and not a transverse profile.
- The target slit aperture needs to be adapted to the beam energy and observation wavelength.
Jitter for different beam sizes

Filter: 450nm Slit: 220um NoMask

Vertical Beam Size 1um

Vertical Beam Size 18um

Vertical Beam Size 30um
ATF2 ODR Optical line upgrade (October 2016)

AIM: Synchronous Imaging and Angular acquisition for position filtering in angular.
Planed ODR upgrade for spring 2016

Upgrading the setup to perform UV/DUV angular beam size measurement.

Going from visible to UV
- Enhance the sensitivity: \( \frac{I_{\text{min}}}{I_{\text{max}}} \)
- Imply the use of a smaller slit to respect the rule:
- Give the possibility to measure smaller beam sizes!
- Optical line under 1mBar vacuum will be needed.

\[ a \approx \frac{\gamma \lambda}{2\pi} \]
Thanks for your attention!
Backup slides
Measuring small beam sizes

As the beam size decreases, the projected OTR vertical polarization component is dominated by the point spread function PSF of the OTR.

The Gaussian fit works fine down to 10 microns beam size.

Then it is still possible to measure smaller beam sizes using the visibility \( \frac{I_{\text{min}}}{I_{\text{max}}} \) of the projected OTR vertical polarization component.
The full OTR PSF profile is of the order of 200 microns size. We use a **11x microscope** configuration in order to get a **peak separation** of about 10 pixels on the CCD. Allow to observe a **clear PSF minima**.

**Diagram:**
- Target Support with lens holder.
- Target
- Mirror
- Filter Wheel
- Polarizer
- CCD
- Camera objective Mag 1:1
- First lens F:30mm in vacuum
Submicron beam size @ KEK-ATF2

ATF2 horizontal beam size $\sim 100\mu m$, vertical $\sim 1\mu m$, 1.3GeV, 1.2nC ($\sim 10^{10}$ e-)

A dedicated poster on submicron-OTR is presented by Konstantin Kruchinin

Averaging 10 shots
The transverse component of the electric field intensity scales linearly with the Lorenz factor $\gamma$. 

**Rest mass electron** electric field map.

**Relativistic electron** electric field map.

**ODR with a slit target**

![Graph showing radial electric field intensity vs. distance from particle]
ODR imaging for orthogonal polarizations

Vertical polarization

Horizontal polarization

Single particle Simulation

320x10um Beam CESR

Intensity $E_x \lambda=400\text{nm} \sigma=200$

Intensity $E_y \lambda=400\text{nm} \sigma=200$

Entries 1442820
Mean $x$ 739.9
Mean $y$ 247.6
RMS $x$ 41.47
RMS $y$ 35.03

Entries 1442820
Mean $x$ 736.9
Mean $y$ 251.5
RMS $x$ 57.32
RMS $y$ 38.24
ATF2 ODR Optical line upgrade
ODR target development

CESR Cornell electron storage ring 2.1GeV

Beam size @ target location 320x10um²

VBSM and XBSM available for beam size cross calibration.

Developing target technology

Understand target and mask interference.
Can we use ODR as an optical BPM?

**Optical BPM properties**
- Easy to find out if the beam is *centered* in the target aperture looking at the profile.
- *Calibration* of the asymmetry *needed* for accurate position measurement.

**Improvements and applications**
- Inclination of each slit side can be different to decouple top-bottom sources.
- The light from each slit side could be read out directly by a photomultiplier.
- Can be used as a directional BPM if two opposite beams pass through.

Possible use of ODR as BPM
LHC Gamma: 6500
Effective ODR field radius:
0.7 mm @ 650nm
Slit aperture 1.4mm
7 mm @ 6.50um (Infra red)
Slit aperture 14mm
=> BPM in collimator?
Comparison with a cavity BPM

The bigger fluctuation is due to the BPM resolution and the larger beam jitter at the BPM position about 40 cm away from virtual IP.
ODR Summing intensified camera images
Filter: 450nm Slit: 105um Mask: 202um

Single Image

10 Images

100 Images

Most of the data sets are 100 images each on the latest ODR runs!
ODR Polarizer scan angular Full 180°
Filter: 450nm Slit: 80um Mask: 156um
ODR using a mask upstream

The **target** slit produce **backward diffraction radiation**. The **mask** slit produce **forward diffraction radiation**. The two **ODR** sources will **interfere** together.

Since the **target and mask slit sizes are different**, the amount of light from each contributor will change leading to a complex **interference pattern** in the angular and spatial domain.

![Diagram of ODR setup with target and mask slit dimensions](image-url)