# DESIGN OF AN OPTICAL DIFFRACTION RADIATION BEAM SIZE MONITOR AT SLAC FFTB

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*Abstract*

We design a single bunch transverse beam size monitor which will be tested to measure the 28.5 GeV electron/positron beam at the SLAC FFTB beam line. The beam size monitor uses the CCD images of the interference pattern of the optical diffraction radiation from two slit edges which are placed close to the beam path. In this method, destruction of the accelerated electron/positron beam bunches due to the beam size monitoring is negligible, which is vital to the operation of the Linear Collider project.

## OVERVIEW

The Optical Diffraction Radiation(ODR) is generated when a charged particle bunch passes by inhomogeneous boundaries, and is considered as the wake field of a beam bunch. By using a tilted conducting slit where a beam bunch passes through the center of the slit aperture, we can observe the interference pattern of the backward scattered ODR from two edges of the conductive slit. The ratio of the photon intensity at the peak of the interference pattern of the ODR and that at the valley of the photon intensity gives the information of the transverse beam size. [1, 2, 3, 4] Because the distances of the edges of the slit from the beam central trajectory is typically 10 times or more larger than the transverse beam size, this beam size monitor is non-invasive, which is essential to minimize the beam loss in beam size monitor. This beam size monitor measures the beam size of a single bunch, and the fraction of the sampling of the beam bunches depends on the speed of the readout system of the interference pattern of the ODR. Most of the experiments on the use of the ODR for a beam size monitor has been done only recently with electron beams up to around 1 GeV at TTF(Tesla), and at ATF(KEK). With the 28.5 GeV e-/e+ beam at the SLAC FFTB (Final Focus Test Beam), the $\gamma$ factor of $5.8 \times 10^4$ allows us to use much larger aperture size than those with lower beam energy, which contributes to reduce the background photons significantly. The test of the beam size monitor by using ODR at the SLAC FFTB provides a unique condition for a non-invasive beam size monitor with the highest beam energy electron and positron beam. The transverse RMS beam size of electron and positron beam at a focal point of the SLAC FFTB are 2 -10 $\mu$m in horizontal and vertical. The FWHM bunch length is 0.7 mm. The intensity of electron and positron beam is $(1-3) \times 10^{10}$ particles/pulse. The normalized transverse emittance are $(30-50) \times 10^{-6}$ m-rad in horizontal and $(3-6) \times 10^{-6}$ m-rad in vertical. The international collaboration, with researchers at KEK, Tokyo Metropolitan University, and at Tomsk Polytechnic University who have done significant R&D on the beam size monitoring with the ODR at the KEK ATF in Japan with the 1.3 GeV electron beam [5], allows us to understand the dependence of the beam size measurement with the ODR on the beam energy and on the level of the background radiation.

## DESIGN OF THE BEAM TEST EXPERIMENT

A schematic diagram of the beam size monitor with the ODR interference pattern measurement and a conventional wire scanner for a cross calibration is shown in Fig. 1.

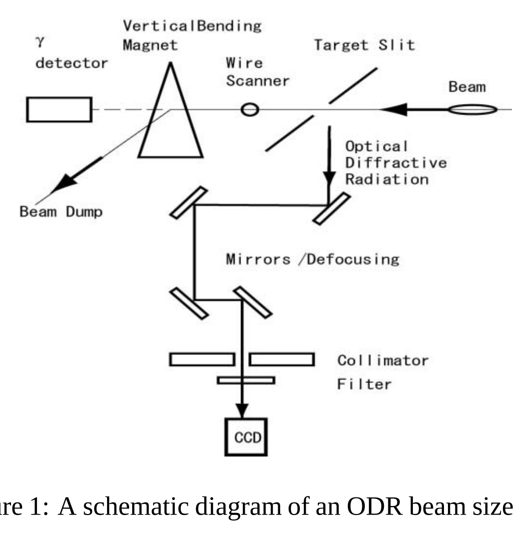


Figure 1: A schematic diagram of an ODR beam size monitor

Because the wavelength of the diffracted optical photon, around 0.5 $\mu$m, is much shorter than the beam bunch length, 0.7 mm, the observed optical diffraction radiation is incoherent, and the optical wavelength allows us to use a simple CCD. The CCD camera is trigger-able with 1000 $\times$ 1000 pixels with 14-16 bits resolution in each pixel. The size of the CCD is 16 $\times$ 16 $mm^2$. The target slit is made

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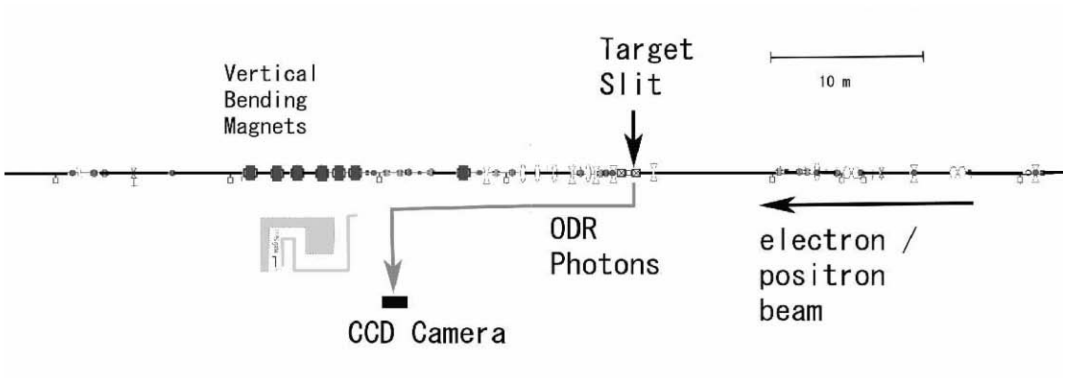


Figure 2: Top view of the experiment layout at the SLAC FFTB

of crystalline wafer/block with 3-5 $\mu$m thick Au conductor coating on the top plane. The slit aperture is around 0.2 mm.

Assuming the typical transverse beam size of 5 $\mu$m(horizontal) $\times$ 5 $\mu$m(vertical), at the SLAC FFTB focal point, the measurement error of the transverse beam size is expected to be around 0.06 $\mu$m in an ideal case by using the interference pattern of the optical diffraction radiation with a bandwidth of 480 - 520 nm. The size of the error of the transverse beam size measurement depends on the level of the background photons into the CCD camera and the stability of the transverse beam size and shape and the location of the transverse center of gravity of the beam. The transverse tail part of the beam interacts with the target slit which generates the optical transition radiation (OTR). Scattered synchrotron radiation of the target slit can also contribute to the background optical photons. [6] The downstream end of the closest dipole and quadrupole magnets are 20 m and 1 m away from the target slit respectively. The total path length of the ODR photons between the target slit and the CCD camera is around 30 m where the CCD camera is located in a measurement room located outside of the FFTB tunnel shield wall. Fig. 2 shows the top view of the experiment area at the FFTB test beam line.

We obtained the simple estimation of the ODR photon yield by using the exact Maxwell equation solution on the infinitely thin ideally conductive semi-plane with the optimal gap width of the target slit at $0.2\lambda\gamma$. The part of the ODR yield within the optimal angular width of $0.1/\gamma$, is estimated as:

$Yield = 5 \times 10^{-5}\gamma^2(\frac{\sigma}{\gamma\lambda})^2$,

where $\gamma$ is the Lorenz-factor, $\lambda$ is the radiation wavelength, $\sigma$ is the transverse beam size with the Gaussian approximation. For $\sigma$ at 10$\mu$m, $\lambda$ at 0.5$\mu$m, and $\gamma$ at 60,000 this value is smaller by a facto of 4 $\times 10^4$ than the ODR yield in the same angular width at the maximum of the ODR angular distribution, and it is smaller by a factor of $10^5$ than the optical transition radiation (OTR) yield in the same angular width at the maximum of the OTR angular distribution. The angular distribution of parallel polarization of an ordinary ODR (in the far field zone) is presented in Fig. 3.

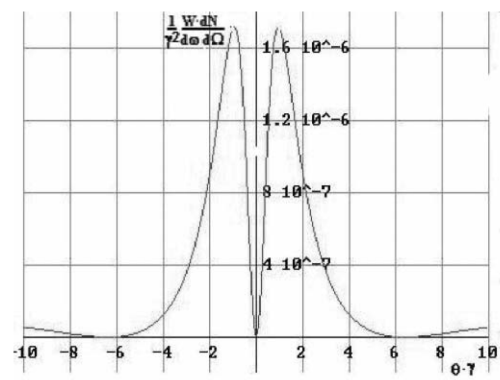


Figure 3: Parallel polarization component of backward ODR intensity from a slit of $0.1\lambda\gamma$ width for $\gamma$ at 60000. Angular distribution in polarization plane, calculated without accounting of the pre-wave zone effect.

The expected number of the optical diffraction radiation photons in the 1 dimensional angle range of 10/$\gamma$ rad within the bandwidth of 480 - 520 nm is around 1 $\times 10^6$ / ($10^{10}$ electron/positron bunch) which is roughly the same as that of the optical transition radiation, if the conducting plate is placed directly in the beam. The number of ODR photons in the bandwidth has weak dependence on the beam energy. Study is underway to investigate the possibility of using the polarization of the optical diffraction radiation in order to suppress the background optical photons into the CCD camera with a polarization filter.

The effect of the total wake field of a beam bunch to the subsequent beam bunches must be calculated with a typical target slit parameters. And the "pre-wave' zone effect must be taken into account in the calculation of the yield of the ODR photons from the target slit.

The nature of the 'pre-wave zone' effect for a backward transition (diffraction) radiation may be explained as follows: if a detector is placed at a distance less than $\gamma^2\lambda$ from a target, then measured radiation characteristics will be distorted in comparison with ones for far field zone. Model of this effect was developed for transition radiation [7, 8] and this one was observed experimentally in the OTR for electron energy at 0.9 GeV. [9] We developed a simpler model of radiation in pre-wave zone which allows us to calculate the transition and diffraction radiation properties for different geometries. Fig. 4 shows the preliminary angular distribution of parallel polarization component of backward ODR intensity from a slit of $0.1\lambda\gamma$ gap width for $\gamma$ at 60000 with the distance of the detector at 5.4m from the target with the pre-wave zone effect.

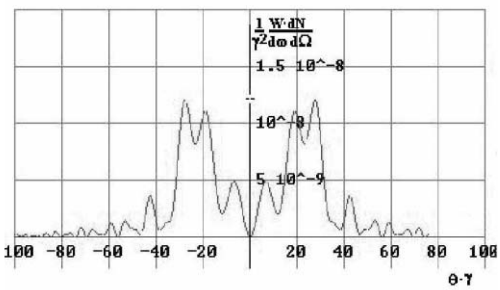


Figure 4: Parallel polarization component of backward ODR intensity from a slit of $0.1\lambda\gamma$ width for $\gamma$ at 60,000. Angular distribution in polarization plane, calculated with the pre-wave zone effect.

The goals of the beam test for the beam size monitor with optical diffraction radiation at the SLAC FFTB are :

1. establish the measurement system of the transverse size of the 28.5 GeV electron and positron beam with the optical diffraction radiation,

2. obtain the size of the systematic error of the transverse beam size measurement by using the conventional wire scanner with multiple beam bunches, or by using the optical transition radiation from a single beam bunch off a slant target plate directly placed in the beam path,

3. optimize the slit plate angle, gap size, and the bandwidth of the optical diffraction radiation for a precise non-invasive beam size monitor,

4. study on the measurement error of the transverse beam size due to the background photons into the CCD camera by:

i) optical transition radiation off the target slit which is generated by the transverse beam tail particles,

ii) scattered optical photons off the target slit material associated with the beam halo, and

iii) synchrotron radiation at the upstream dipole magnets and quadrupole magnets.

The key issues are to use conventional wire scanners and the optical transition radiation for cross-calibration of the beam size measurement, and to understand the background optical photons at the SLAC FFTB. The challenges of this beam test are to achieve the required flatness of the conductive slit surface, and to resolve the small opening angle between the interference pattern peaks within a reasonable distance without distortion.

## SUMMARY


We design a single bunch transverse beam size monitor which will be tested to measure the 28.5 GeV electron/positron beam at the SLAC FFTB beam line. The beam size information is given by the ratio of the ODR photon yield in the valley and that in the peak. But the information is distorted by the pre-wave zone effect of the ODR photons, and it is smeared and offset-ted by the background photons by the optical transition radiation by the transverse beam tail particles, the synchrotron radiations through the magnetic elements, and the beam halo. Work is in progress in finding the optimum parameters of the ODR beam size monitor which gives the maximum information on the transverse beam size with those distortion effects and backgrounds.


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