DEVELOPMENT OF THE NON-INVASIVE BEAM SIZE MONITOR USING ODR

T. Muto*, S. Araki, H. Hayano,P. Karataev, N. Terunuma, J. Urakawa, KEK,Ibaraki,Japan
H. Hamatsu,Tokyo Metropolitan University, Tokyo,Japan
G. Naumenko, A. Potylitsyn, Tomsk Polytechnic University, Tomsk, Russia

Abstract

We present recent development of the non-invasive beam size monitor using optical diffraction radiation(ODR) constructed at KEK-ATF. We have performed the beam size measurement by the ODR from a slit target using a ultra-low emittance electron beam extracted from KEK-ATF damping ring. To confirm the beam size at the ODR target, the tungsten wire($\phi = 10\mu$m) was newly installed in the target mount.

We present first results of the comparison of the beam size measured by the ODR monitor and the wire scanner.

INTRODUCTION

Extremely low emittance and high current electron beam is one of vital characteristics for linear colliders and X-ray FEL's. Parallel developments of non-invasive beam diagnostics are strongly required for realizing such beams. The conventional invasive diagnostics like solid wire scanner or transition radiation monitor can not be applied for such a high quality electron beam because of significant emittance growth or target destruction. Detection of incoherent diffraction radiation in visible region called ODR, because of non-destructive nature, is the most promising technique for application to non-invasive beam diagnostics. In addition, the ODR beam size monitor makes it possible to measure the beam-size for a single shot.

Experiments on ODR using extremely low emittance electron beam extracted from the KEK-ATF(Accelerator Test Facility for Linear Colliders)[1][2] damping ring have been performed since the year 2000. The bunch length was 9mm ($=$ 30ps). Therefore, diffraction radiation was incoherent radiation in considered wave length region($\lambda < 1\mu$m). The first observation of the ODR from a single edge has been performed by us[3]. The results of measurements was consistent with the theoretical expectation.

BEAM SIZE MEASUREMENT USING THE ODR

ODR is emitted when a charged particle passes through a vicinity of a conducting target.

When an electron passes between two semi-planes(See Fig.1), radiations are emitted in the direction to specular reflection from both halves and produce interference pattern. If the electron trajectory has a offset from a center of the slit (b in Fig.1), that interference pattern is diluted.

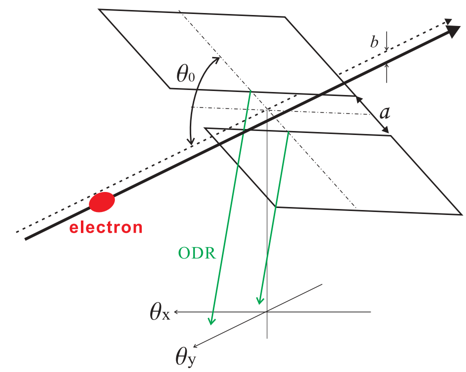

Figure 1: Geometry of ODR from a slit target

The theoretical approach has been performed in [4]. In that paper, only vertical polarization component is sensitive to vertical beam size for this geometry. When the electron beam has a Gaussian distribution(the rms beam size is σ_y), the angular distribution of it convoluted with the Gaussian is,

$$\frac{dW_y}{d\omega d\Omega} = \frac{\alpha\gamma^2}{2\pi^2}\frac{\exp\left(-\frac{2\pi a \sin\theta_0}{\gamma\lambda}\sqrt{1+t_x^2}\right)}{1+t_x^2+t_y^2}\times \left\{\exp\left(\frac{8\pi^2}{\gamma^2\lambda^2}\sigma_y^2\left(1+t_x^2\right)\right)\cosh\left(\frac{4\pi b}{\gamma\lambda}\sqrt{1+t_x^2}\right) - \cos\left(\frac{2\pi a\sin\theta_0}{\gamma\lambda}\theta_y+\psi\right)\right\} \quad (1)$$

where α is the fine structure constant, γ is the Lorentz factor, a is the slit width, θ_0 is the inclined angle of the target from the particle trajectory, λ is the ODR wavelength, b is the beam offset from the center ,$t_{x,y} = \gamma\theta_{x,y}$ are the observation angles from the direction of specular reflection in unit of the γ^{-1}(See Fig.1) and $\psi = \arccos\frac{1+t_x^2-t_y^2}{1+t_x^2+t_y^2}$.

For practical purposes, it is best way to measure the projection over θ_x. The projection calculated for two different beam sizes and the optical transition radiation (OTR), which is well-known and widely used in accelerator region, is shown in Fig.2. One may see that the interference pattern is deformed while the beam size increases, specially the intensity at $\theta_y = 0$ is strongly depends on the beam size. By taking the minimum-to maximum intensity ratio, we can obtain the beam size. Fig.3 shows the beam size dependence of the ratio. In Fig.3, the intensity ratio doesn't

* tmuto@post.kek.jp

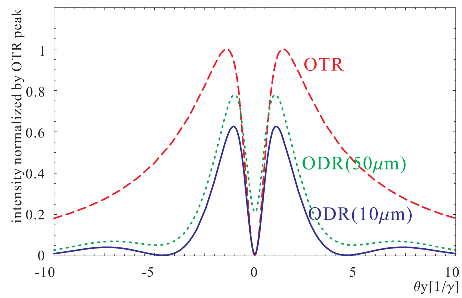

Figure 2: the projected vertical polarization component. solid line is for $\sigma_y = 10\mu\text{m}$, dotted line is for $\sigma_y = 50\mu\text{m}$ and dashed line is the OTR.

reach to zero at $\sigma_y = 0\mu\text{m}$. Because we assume the finite angular acceptance to fit to the experimental condition.

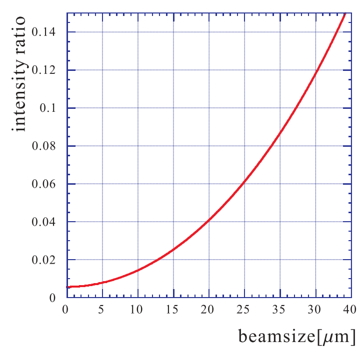

Figure 3: minimum-to-max-mum intensity ratio vs beam size at $\lambda = 550 \pm 20$nm,$\Delta\theta_y = 0.142[1/\gamma]$,$\Delta\theta_x = 15.6[1/\gamma]$

EXPERIMENTAL SETUP

The ODR measurement system has been installed at extraction line of KEK-ATF. KEK-ATF provides a 1.28GeV($\gamma \sim 2500$) single bunch electron beam with low emittance extracted from the damping ring. The experimental setup is shown in Fig.4.

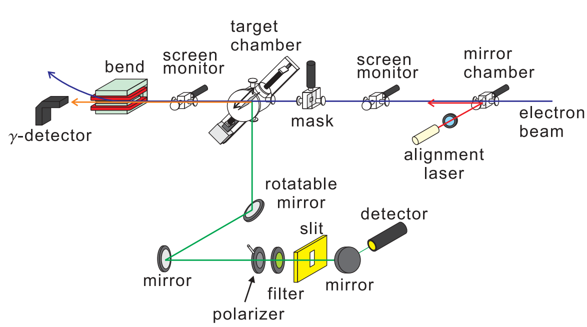

Figure 4: Experimental setup

The measurement system is composed of alignment laser system, two screen monitor, Mask, ODR target chamber(a slit target and a wire), rotatable mirror, plane mirrors, polarizer , optical filter, slit, photo-multiplier tube(PMT) and Air Cherenkov counter as γ-ray detector.

The target holder is mounted at 45° from beam line in the target chamber and actuated by a pulse motor stage. The target position can be read by using a linear gauge. The accuracy of position reading is $0.5\mu\text{m}$.

Target is set in the target holder. ODR slit target is a silicon wafer($7 \times 9 \times 0.3t$ mm) coated with gold. The silicon has a 0.25×5mm hole. Emitted light from target surface (ODR etc.) goes down and reflected by a two-axis rotatable mirror which is rotated for angular distribution measurements. The rotatable mirror and light detector are placed at the distances 0.92m and 3.55m from the target.

PMT(Hamamatsu H1161) is used as a light detector. This detector spectral response range is from 300nm to 650nm. The polarizer(for measuring only vertical component),the optical filter with 550 ± 20nm wavelength and a slit with 0.2×24mm aperture are located in front of PMT. Since the distance from the target and the slit size, the angular acceptance is $\Delta\theta_x = 15.6\gamma^{-1}$ and $\Delta\theta_y = 0.142\gamma^{-1}$.

The optical alignment was performed using the laser alignment system. In this experiment, laser beam was adjusted within hundred μm accuracy at each screens. And a distance between two screen monitors was 4.8m, so direction alignment was adjusted less than 42μrad.

In Ref.[3], it is shown that the synchrotron radiation(SR) from magnets in the extraction-line (the main source is the nearest bending magnet) is the background source. To avoid SR contribution, the mask was installed at 0.3m upstream the target. The mask is ceramics with 1×2mm hole[5].

We also installed a tungsten wire($\phi = 10\mu\text{m}$) in the target chamber. By scanning this wire, we can measured the beam size at the ODR source point.

A lead converter and air Cherenkov light detector are used for measuring γ-ray scattered from targets and the wire.

RESULTS

First, we measured the emittance of electron beam using five wire scanners in extraction line. Measured emittances were $\epsilon_x = 1.9 \times 10^{-9}$mrad and $\epsilon_y = 3.1 \times 10^{-11}$mrad. Using this parameter, we prepared three optics calculated by SAD[6] with $\sigma_y = 10, 16, 27\mu\text{m}$.

In these optics almost all quadrupole and steering magnets located downstream of the last bending magnet were switched off in order to reduce the SR. At the start and the end of mesurement for each optics set, we confirm the beam size. The variation of the beam size was about $1\mu\text{m}$ at each sets.

Fig.5 shows one example of measured ODR distribution. One may see the clear interference pattern.

As seen in eq.(1), the beam position aeffects the angular distribution in the same way as the beam size. Therefore, we measured the ODR angular distribution as a function

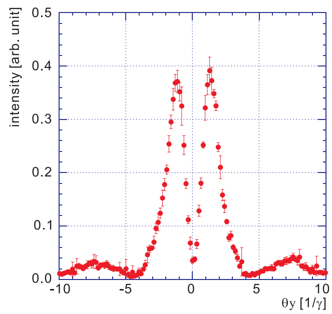

Figure 5: Measured ODR angular distribution

of target position at each beam optics set. In the case of $\sigma_y = 15\mu$m optics, the target position dependence of the intensity ratio is shown in Fig.6. By making the parabolic fit to the measured dependence, we could determine the minimum-to-maximum intensity ratio corresponding to the slit center.

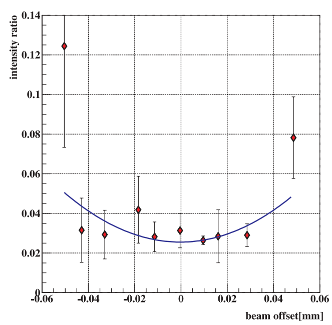

Figure 6: Measured intensity ratio vs the target position at $\sigma_y = 15\mu$m optics.

In Fig.7, we summarize the beam size measurement by ODR technique and wire scannings. From Fig.7, one may see that the ODR measurements has the sensitivity to the electron beam size. However, the beam size measured by the ODR was slightly larger than by the wire scanning. It indicates that there are some systematic error in these measurements. During these measurements, the extraction kicker timing was unstable, therefore we had to control the timing. That timing instability will causes mainly the horizontal beam position jitter, however, if some coupling source between horizontal and vertical orbit existed, vertical orbit will also have a jitter.

SUMMARY

We performed a first trial of the comparison between the beam size measured by ODR technique and wire scanning methods. The beam size measured by ODR has a sensitivity around 20μm electron beam size. However, the results also indicate that there are some systematic errors. We should understand this reason and eliminate it to measure 10μm beam size. We also perform the measurement with various wavelength region using optical filters. The our final goal is the single shot beam size measurements. To this purpose we are considering a new detector system based on a multi-anode PMT or an image intensified CCD camera.

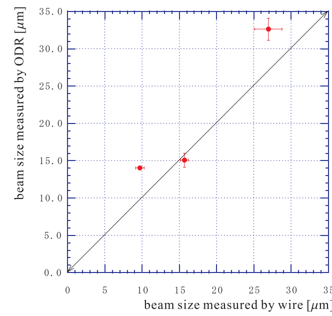

Figure 7: The comparison between measured by the ODR technique and wire scanning

ACKNOWLEDGMENTS

This research was partially supported by Grand-in-Aid Scientific Research (No. 15540301-00) from Ministry of Education, Culture, Sports, Science and Technology(MEXT) of Japan. Two of authors(T. Muto and P. Karataev) acknowledge the support of Postdoctoral Fellowship of the Japan Society for the Promotion of Science(JSPS).

REFERENCES

[1] J. Urakawa et al., Nucl. Instr. Meth A**472**, 309 (2001)

[2] K. Kubo et al., Phys. Rev. Lett **88**,194801(2002)

[3] T. Muto et al. ,Phys. Rev. Lett **90**,104801(2003)

[4] M. Castellano, Nucl. Instr. Meth A**394**,275(1998)

[5] P. Karataev et al.,"Optical Diffraction Radiation Beam Size Diagnostics Development At KEK Accelerator Test Facility",EPAC'04,Lucerne July 2004,these proceedings.

[6] http://acc-physics.kek.jp/SAD/sad.html