First Stage Experiment on Optical Diffraction Radiation at KEK-ATF

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Abstract

Recently we have started a series of experiments to develop non-invarsive electron beam diagonostics based diffraction radiation at KEK-ATF.

First stage experiment is to investigate of Optical Diffraction Radiation from a single slit.

A mesurement system has been installed at KEK-ATF. To verify accuracy of the measurement system, we measured angular distribution of well-known optical transition radiation,which is close to diffraction radiation's nature. In this paper, we will show the mesurement system and some preliminary results of the OTR measurement.

1 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. Detection of Optical Diffraction Radiation(ODR), because of non-destructive nature, is the most promising technique for application to non-invasive beam diagnostics, however, a very little experimental investigations existed[1][2]. These experiments are the mesurement of electron bunch form using coherent diffraction radiation in millimeter and sub millimeter wavelength regions.

A series of experiments on ODR using low emittance electron beam extracted from the KEK-ATF(Accelerator Test Facility for Linear Colliders)[3] damping ring has been performed. Experiments aimed for investigating general characteristics of the optical diffraction radiation and establishing a scheme of measurement of the optical diffraction radiation for applications to a new non-invasive beam diagnostics in more realistic accelerator environments. Final goal is to measure transverse beam size of high intensity, low emittance beam like linear colliders and X-ray FEL's.

First stage of experiments is to investigate ODR from a single edge. For detailed ODR investigation, we constructed a measurement system and measured Optical Transition Radiation(OTR), whose characteristics are well-known and close to ODR's nature, in order to verify the performance of the mesurement system.

2 ODR AND OTR CHARACTERISTICS

ODR is emitted when a charged particle passes throuh the vicinity of the optical discontinuities, if the distance to optical discontinuities h(impact parametar) satisfies a condition

$$h < \frac{\gamma\lambda}{2\pi} \tag{1}$$

where γ is Lorentz factor and λ is ODR wavelength.

There are two radiation direction. One is along the direction of particle velocity (foward radiation) , the other is along the direction of specular reflection (backward radiation).

When a particle passes throuh the vicinity of semi-infinite plane at 45° incident angle, backward radiation is detected at 90° angle from the particle trajectry.

In relativistic electron case, angular distribution of ODR is given by,[4][5][6]

$$\frac{d^2W}{d\omega d\Omega} = \frac{\alpha}{4\pi^2}\exp\left(-\frac{\omega}{\omega_c}\sqrt{1+\gamma^2\theta_x^2}\right)\frac{\gamma^{-2}+2\theta_x^2}{\left(\gamma^{-2}+\theta_x^2+\theta_y^2\right)^2} \tag{2}$$

where α is fine-structure constant, $\omega_c = \gamma\beta/2\alpha(\hbar = m = c = 1)$ and the angle θ_x, θ_y are shown in Fig.1

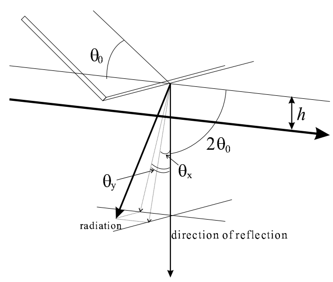

Figure 1: Geometry of DR near semi-infinite target

On the other hand, OTR is emitted when a charged particle crosses the boundary between two media with different dielectric constants. There will be OTR foward radiation and backward radiation like ODR.

In relativistic electron case, angular distribution of OTR is given by,[7]

$$\frac{d^2W}{d\omega d\Omega} = \frac{\alpha}{\pi^2}\frac{\theta^2}{(\gamma^{-2}+\theta^2)^2} \quad (3)$$

where $\theta^2 = \theta_x^2 + \theta_y^2$ is the angle between the observation direction and the direction of specular reflection. From Eq.3, there is maximum at $\theta_{max} = 1/\gamma$ and symmetric distribution for azimuthal direction around radiation axis.

3 EXPERIMENTAL SETUP

The ODR and OTR 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 setup is shown in Fig.2. The measurement system is composed of alignment laser system, two screen monitor, ODR target chamber, rotatable mirror, slit, photo-multiplier tube(PMT) and γ-ray detector.

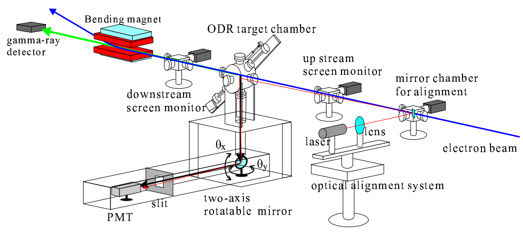

Figure 2: experimental setup

A detail of the ODR target chamber is shown in Fig.3. 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 5μm. In ODR experiment, we can controll impact parameter by the pulse motor with this accuracy.

Two targets are set in the target holder(Fig.4). One of them is ODR single edge target, which is 100μm aluminium target. The roughness of ODR target is less than Ra= 0.3μm. Another one is OTR target, which is 200μm thick aluminium plate. OTR target is turned off by diamond turning tool. The roughness is almost same as the ODR target.

Backward OTR light goes down and reflected by a two-axis rotatable mirror. The two axis rotatable mirror are rotated by micromotor head actuators controlled by PC which is placed outside of tunnel. The rotatable mirror and light detector are placed at the distances 0.97m and 1.35m from the target. Since angle resolution of the rotatable mirror is $\sim 35\mu$rad, the resolution of OTR angular distribution is less than 10μrad.

PMT is used as a light detector. A slit,which can be changed horizontal and vertical width independently, is located in front of PMT.

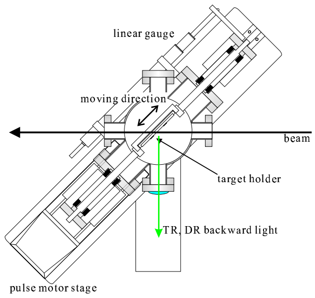

Figure 3: detail of ODR chamber (side view)

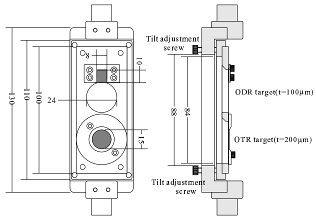

Figure 4: target holder

The measurement system was aligned using a laser. Optical system is composed of a He-Ne laser, a spatial filter and focusing lens(f=100mm). These compornents are on one optical base. And the base can be adjusted both of position and direction each horizontal and vertical using micrometers and adjustable screws. The laser light is lead into beam pipe by the mirror chamber.

An alignment method is following. First, the electron beam and the alighnment laser position is mesured using two screen monitors placed upstream and downstream of ODR target chamber. Laser light position on the two screens are adjusted into electron beam position by using laser stand screws. After inserting targets, the rotatable mirror, the slit and the PMT are aligned using reflected laser light from the target.

A lead convertor and air cherenkov light detector are used for measureing γ-ray scatterd from targets.

4 EXPERIMENTAL RESULTS

The optical alignment was performed at first. The beam positions at the two screen monitors were recorded by capturing th ebeam profile image in advance. In order to determine beam axis on ODR, OTR targets, focused laser light created by optical alignment system was introduced into the beam chamber from the upstream mirror chamber. Laser light positions on the screens were tried to adjust into recorded beam position by positioning of optical alignment system. In this experiment, laser beam was adjusted within a few mm accuracy. The reason of this insufficient accuracy was coming from small mirror acceptance of the mirror chamber. It will be improved in the next experiment. During this optical detector alignment using reflected laser beam at the target, we found a surface deformation on the ODR target. Therefore only the OTR target was used for the alignment and the beam experiment.

Tn the beam experiment, the impact parameter h is the key parameter for the ODR measurement. In order to determine the target edge position precisely, scatterd γ-ray intensity was measured as a function of the target position, shown in Fig.5. A differenciated distribution of this plot will determine the beam profile and the beam center position. Though several scans were examined, the accuracy of the beam center position was not enough for the ODR experiment. The accuracy of the target position reading(5μm) will be improved to 0.5μm in the next measurement.

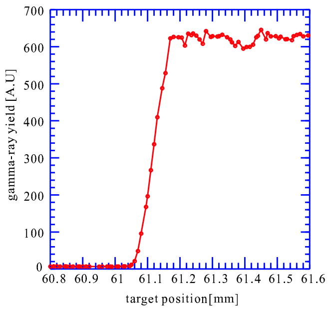

Figure 5: ODR target position dipendence of γ-ray yield

For the evaluation of the measurement system performance, OTR light angular distribution was measured and compared with theoretical distribution. The beam was operated in single bunch, 1.28GeV energy, 1.56Hz repitition extraction with 5×10^9 electrons intensity. the beam size at the target was estimated to $\sim 80\mu m$ horizontal and $\sim 8\mu m$ vertical. The slit width in front of the PMT was set to $500\mu m$ for both horizontal and vertical. The 1100V HV voltage of the PMT was applied. The single from the PMT was converted by charge sensitive ADC with 200ns gate integration. Two dimensional angular distribution of OTR is shown in Fig.6. The step size of this scan was 0.1 mrad, and scaning range were $\pm$2mrad. The overall distribution is shown in Fig.6(a), and zoomed view of $\pm$0.8mrad in Fig.6(b). The distribution was not symmetric. In order to compare the angle between two maxima, θ_y cut view is shown in Fig.8 and θ_x cut view in Fig.7. The mesured opening angle of the two maxima was around 0.6mrad, on the other hand, theoretical angle $\theta_{\max} = 1/\gamma = 1/2500 = 0.4mrad$. The discrepancies of asymetric distribution and opening angle seems to be coming from the surface deformation of the target, alignment error of the optical axis and accuracy of light detection system.

5 SUMMARY

We have performed a series of ODR experiment. First purpose is to investigate ODR light from single edge. We measured well-known OTR angular distribution to verify our mesurement system.

OTR angular distribution was measured,but deformed. The conciderable reasons of these problems are deformation of targets , alignment error of optical axis and accuracy of light detection system. They will be investigated in a few month.

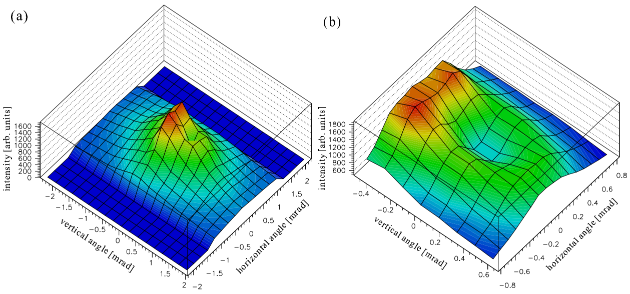

Figure 6: 2D angular distribution of OTR.(a)all region (vertical angle;-2.0mrad $< \theta_y <$ 2.0mrad, horizontal angle;-1.0mrad $< \theta_x <$ 1.0mrad), (b)zoom view (-0.42mrad $< \theta_y <$ 0.64mrad, -0.8mrad $< \theta_x <$ 0.8mrad)

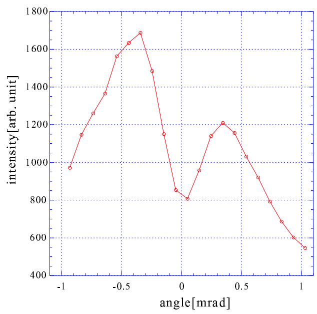

Figure 7: θ_y angular distribution at $\theta_x = 0$

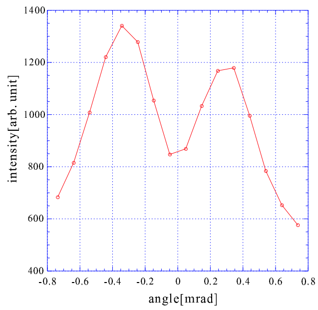

Figure 8: θ_x angular distribution at $\theta_y = 0$

Once established performance of the system, the yield, the angular distribution, and the spectral distribution of ODR as a function of the target position will be measured.

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