DEVELOPMENT OF THE HIGH RESOLUTION ELECTRON BEAM PROFILE MONITOR FOR MEDICAL X-BAND LINAC

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Abstract

An optical transition radiation (OTR) has potential for beam diagnostics, because beam emittance and energy can be deduced from its angular distribution. In order to investigate the possibilities offered by this OTR based technique for inversed Compton scattering hard X-ray source based X-band linac, we have performed an experiment by an S-band linac at Nuclear Engineering Laboratory, University of Tokyo.

INTRODUCTION

Precise electron beam diagnostics hold an important position for a stable generation of hard X-ray by compact inversed Compton scattering [1] [2].

In general, the screen monitor (luminescence screen) is widely used for beam position and profile measurement. It is also used for emittance measurements by QUAD scan method. Although the luminescence screen is simple and useful, the adaptation to small size beam (<100μm) is difficult because of a blur depending on its thickness.

In order to solve this problem, a utilization of optical transition radiation (OTR) is proposed for the beam diagnostics[3]. The spatial resolution defined by a diffraction limit due to a wavelength of OTR is much smaller than that of luminescence screen. In addition, an angular distribution of OTR depends on beam energy and emittance, therefore the OTR measurement can be also utilized as energy and emittance monitors[4]. A lot of experiments have been done for high energy beam during the past years. For example, the strong potential of transition radiation for single shot emittance and beam energy measurement had been demonstrated. OTR interferometry using two-foil also developed [5][6] and has shown its capability to enhance the performance of the OTR angular techniques.

In this article, we report on the investigation of OTR utilized as the beam monitor for low energy beam. Experiments have been performed at Nuclear Engineering Research Laboratory (NERL), University of Tokyo using an S-band linac with a photocathode RF injector. The linac produces a single bunch electron beam with the energy of 20 MeV and charge of 1nC.

THEORY OF TRANSITION RADIATION

The OTR occurs when a charged particle passes a boundary between two media with different dielectric constant[7]. Using the formalism developed in [7], the angular distribution from a single electron at the observation plane (vertical and horizontal) can be expressed as [8]

$$\frac{d^2W_x}{d\omega d\Omega}=\frac{e^2}{4\pi^2c}\frac{\beta^2\sin^2\theta_x}{(1-\beta\cos\theta_x)^2}\frac{1}{(1-\theta_x\cot\theta_0)^2}, \qquad (1)$$

$$\frac{d^2W_y}{d\omega d\Omega}=\frac{e^2}{4\pi^2c}\frac{\beta^2\sin^2\theta_y}{(1-\beta\cos\theta_y)^2}, \qquad (2)$$

where θ_x and θ_y are the angle between the observed direction and the direction of seculars reflection, θ_0 is the angle between the beam trajectory and OTR target. Fig.1 shows the angular distribution calculated by Eq.(1) and (2) for θ_0=45° and γ=39.1(E=20MeV). Here, zero-emittance is assumed. Angles at peak depend on the beam energy, and they are approximately equal to 1/γ.

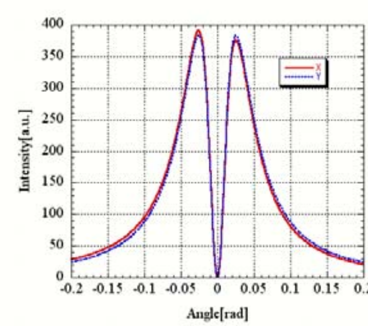

Figure 1: The OTR angular distribution. solid line: horizontal, doted line: vertical.

Assuming that the divergence of electron beam has a Gaussian distribution defined as:

$$D(z)=\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{z'^2}{2\sigma_{z'}'^2}\right), \quad (z=x,y), \qquad (3)$$

the angular distribution is described as convolution of Eq.(1) or (2) and Eq.(3).

$$\frac{d^2W'}{d\omega d\Omega}=\frac{e^2}{4\pi^2c}\int_{-\infty}^{\infty}\frac{(\theta-z')^2}{\left((\theta^2-z')^2+\gamma^{-2}\right)^2}\exp\left(-\frac{z'^2}{2\sigma_{z'}'^2}\right)dz' .(4)$$

In figure2, some distributions are given for different emittances. As shown in fig. 2, ratio of peak to zero-radian amplitude is determined by the divergence.

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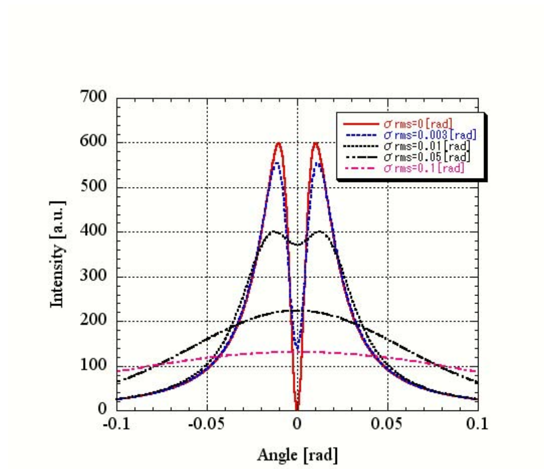


Figure 2: The OTR angular distribution for different value of beam divergence.

Emittance is defined as Eq.(4) when the beam focused on the waist. [9][10] .

$$\varepsilon^{n}_{rms} = \beta\gamma\sigma_{x,y}\sigma'_{x,y} \quad , \qquad (4)$$

where $\sigma_{x,y}$ is the x(y) rms beam size and $\sigma'_{x,y}$ is the x(y) rms beam divergence defined as Eq.(3). Thus the emittance can be measured by only two (profile, angular distribution) images.

EXPERIMENT

The experimental setup is shown in Fig.3. The electron beam is produced from the S-band linac which consists of the photocathode RF injector and a 2-m accelerating tube with 2/3π mode travelling wave structure. An aluminium coated glass substrate (1mm) was installed just downstream of quadrupole pair at the end of linac, and tilted in 45° for the electrons trajectory. An optical system consists of an achromatic lens with 85mm focal length and an intensified CCD camera located at the focal point. The backward-reflected OTR was measured. The near field resolution was determined by a pixel size of CCD, which is 24 μm/pixel. The far field resolution when adjust the focal plane to infinity was 156mrad (around 6/γ).

The image analysis is performed as follows: we first determine the centre of angular distribution, and slices thin along the vertical and horizontal direction around this position. After select the slices of angular distribution, comparison with calculation result was done. A minimization fit gives then the divergence and energy of the beam.

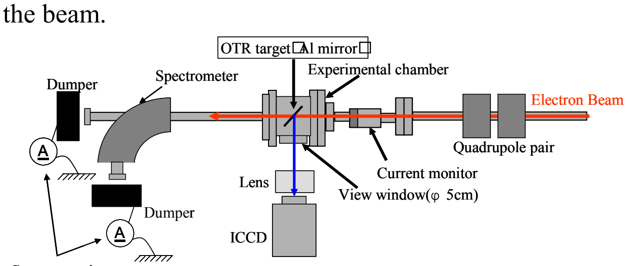
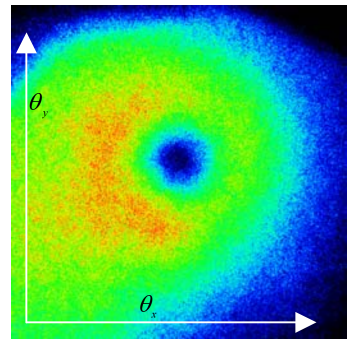


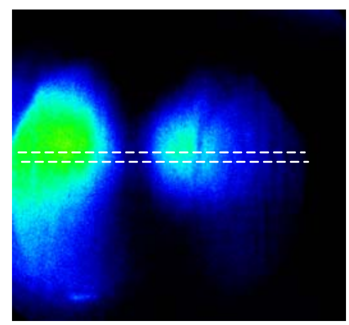
Figure 3: Experimental setup on NERL Univ. of Tokyo beam line.

Emittance Measurement by OTR angular distribution

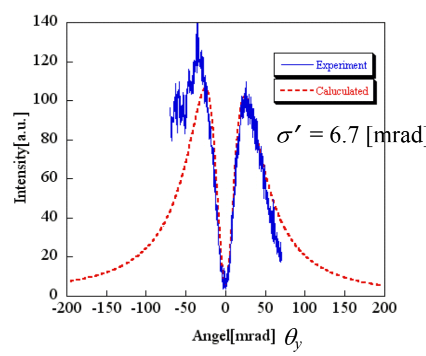
A typical raw image of OTR is shown in Fig.4, (a). Figure 4 (b) and (c) show the horizontally and vertically polarized angular distribution respectively, when the beam is focused to waist. Dot lines indicate the theoretical profiles.



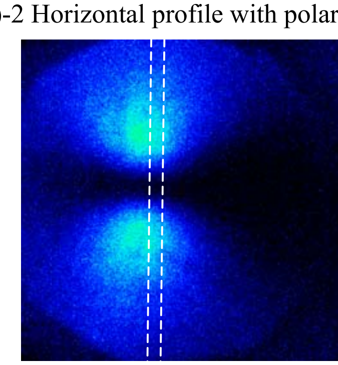
(a) Angular distribution of OTR



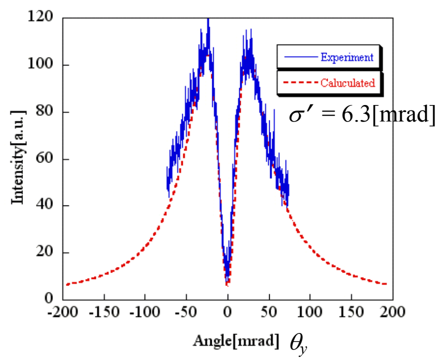
(b)-1 Horizontal image with polarizer



(b)-2 Horizontal profile with polarizer



(c)-1 Vertical image with polarizer



(c)-2 Vertical profile with polarizer

Figure 4 : Angular distribution of OTR(a): OTR angular distribution taken by ICCD camera. (b): Horizontal profile when the beam focused x-waist. (c): Vertical scan when the beam focused y-waist.

The measured distributions are different from the calculation curve; experimental result has asymmetry at left side as shown in Fig.4 (a). This is caused by the cherenkov light from the substrate of aluminium coated glass. Fortunately, the cherenkov light from the glass is not polarized, but the OTR light is polarized radiation. Therefore, a polarizer was located in front of the CCD camera to reduce the cherenkov light. Figure (b) and (c) shows the OTR image passing through the polarizer.

From these figures, the beam divergence was obtained to be 6.7 [mrad] for horizontal and 6.3 [mrad] for vertical. The results of emittance measurement are summarized in table 1, where σ_{rms}[mm] shows the rms beam size at the x and y beam waist. Q-scan shows the result by QUAD scan method based on OTR near field image.

Table 1: Comparison of emittance measurement results

unit : πmm-mrad

	σ_{rms}[mm]	σ'_{rms}[mm]	ε^{n}_{rms}	Q-san
Horizontal	0.13	6.7	35.4±1.3	34.3±0.8
Vertical	0.11	6.3	28.7±1.1	26.5±0.5

Energy Measurement by OTR angular distribution

Fig.5 indicates a comparison between the energy measurement of OTR method and that of analyzer magnet. The results are consistent within a difference of a few MeV. We may consider that a reason of the difference is caused by a bad beam-position into the analyzer magnet.

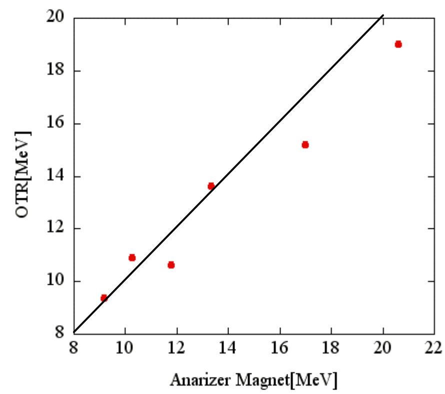


Figure 5: Comparison of the energy measurement (OTR versus analyzer magnet) results.

CONCLUSIONS

Principle verification of emittance and energy measurement by OTR method for the low energy beam were performed by the S-band linac at NERL, University of Tokyo.

With regard to the emittance measurement, the results by far field image is in good agreement with that by QUAD scan method. As for the energy measurement, the accuracy of analyzer magnet will be improved in order to evaluate the accuracy of OTR far field method more precisely. However, we have obtained a possibility of OTR method utilizing as convenient beam monitors.

In next September, we will perform the measurement of beam profile, emittance and energy using this OTR based method at X-band linac for compact hard X-ray source.

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