STUDY ON LONGITUDINAL PHASE-SPACE OF HIGH-BRIGHTNESS ELECTRON BEAMS AT ISIR, OSAKA UNIVERSITY

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Abstract

In order to measure the longitudinal phase-space profile of the electron beam, we are developing the measurement system consisted of a Cherenkov radiator, a bending magnet and a streak camera. The Cherenkov radiator with an aerogel was installed in the beam transport line, and a preliminary longitudinal phase-space image was reconstructed from energy sliced images.

INTRODUCTION

The high brightness electron beam used for the production of Self-Amplified Spontaneous Emission (SASE) is produced with multiple bunch compression processes and its peak current reaches to a few kilo-amperes. These processes effect on a correlation between longitudinal positions of electrons in the bunch and their energies. In addition, the high current electron bunch induces electromagnetic fields, namely "wake fields", in accelerating structures. Since the wake fields are superimposed to the accelerating fields in the structures, the electron bunch experiences the field distorted from a sinusoidal wave. Thus electrons in the high brightness electron bunch have more complicated distribution in the longitudinal phase-space. Until now, there was no method directly to observe the electron distribution in the longitudinal phase-space, and the temporal profile and the energy distribution of the bunch were evaluated individually. Recently, several types of methods are extensively under study to evaluate the longitudinal phase-space profile of the electron beam [1-4].

A measurement system of the longitudinal phase-space distribution of electrons using the combination of a bending magnet, a profile monitor and a streak camera are currently under development at the Institute of Scientific and Industrial Research (ISIR), Osaka University. In the preliminary experiments using an optical transition radiation (OTR) monitor as the profile monitor, it was confirmed that the monitor had higher momentum resolution rather than the ordinary used momentum analyzer using a slit and a current monitor [5]. However, we could not get the efficient number of photons to obtain the phase-space images since, in addition to low photon yield, the angular distribution of the OTR is too large to concentrate in the electron energy region of 10 – 20 MeV, which is suitable energy for THz-SASE and THz-FEL experiments conducted at this laboratory [6-7]. In order to increase the number of photons, we try to use a Silica aerogel as a profile radiator using example from the results at PITZ [2]. In this contribution, we will present preliminary experimental results of the longitudinal phase-space measurements.

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DESIGN OF CHERENKOV RADIATOR

Due to the physical limitation at the installation location, we could not bring a complicated mechanism into a vacuum. We designed a simple radiator supported with a metallic mirror as shown in Figure 1. In this radiator, we use a hydrophobic silica aerogel (SP-50, Matsushita Electric Works, Ltd.). A thin aerogel with a dimension of 45 x 30 mm^2 and a thickness of 1.5 mm is mounted on an aluminium metallic mirror. Refractive index and density of the aerogel are 1.05 and 0.19 g/cm^3, respectively. Cherenkov radiation is emitted in a cone having a subtended angle $2\theta_{CR}$, which is determined by the average index of refraction in the medium n and the particle velocity β as follows:

$$\cos\theta_{CR} = \frac{1}{\beta n}. \tag{1}$$

For electron energies above 10 MeV, the emission angle is almost constant and the subtended angle is 35.5°. Since the angle is too large to gather all rays of light, we use a part of the Cherenkov light. The light is reflected by the metallic mirror into the aerogel again, and is refracted by the surface between the aerogel and a vacuum. In order that the direction of the Cherenkov radiation emitted upward in the aerogel may be perpendicular to the horizontal plane in a vacuum, the radiator is attached with a tilt angle of 55.8. Hereby the effective thickness of the aerogel becomes 2.7 mm. A part of the Cherenkov light cone is taken out from the vacuum chamber to the air through a sapphire vacuum window and is transported to

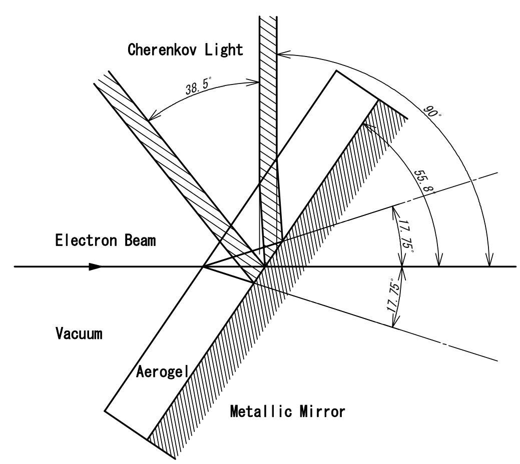

Figure 1: Schematic design of the Cherenkov radiator.

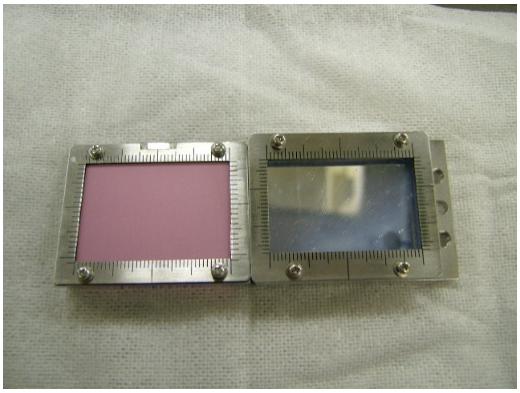

Figure 2: Screen folder mounted with both of a ceramic screen and a Cherenkov radiator. The left screen is a profile monitor with a fluorescence ceramic screen with a thickness of 0.1 mm and it is tilted vertically by an angle of 45°. The right screen is the aerogel radiator and it is tilted of 55.8°.

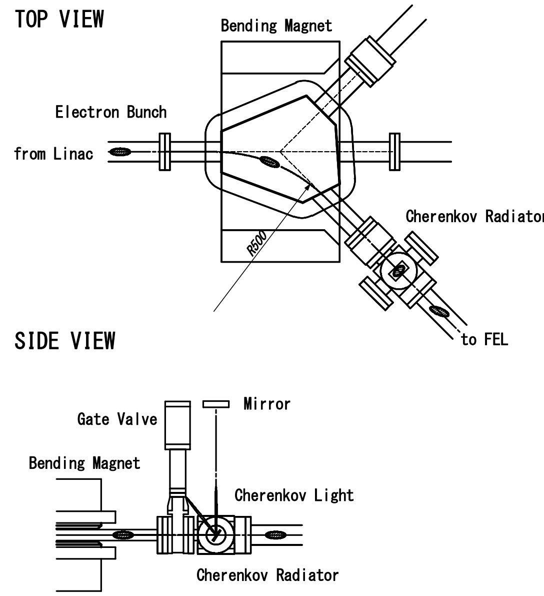

Figure 3: Configuration of the Cherenkov radiator.

the streak camera by mirrors. The light accepted by the first concave mirror is estimated approximately to 10 % of the total radiation. The number of photons N_{CR} radiated in the wavelengths between λ_1 and λ_2 per a distance d along the path of the electrons is represented as follows:

$$N_{CR} = 2\pi\alpha d\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\sin^2\theta_{CR}, \qquad (2)$$

where α is the fine structure constant. Assuming that the average transmittance of the aerogel is 85 % in the wavelength range from 400 nm to 800 nm, the photon yield on the first mirror is expected to 1.2 photons per incident electron. The yield of Cherenkov radiation is larger than that of OTR by two orders of magnitude.

Figure 2 shows the photograph of the screen folder mounted with the Cherenkov radiator. In order to measure the beam profile at the same location, a fluorescence ceramic screen (AF995R, Desmarquest) with a thickness of 0.1 mm is mounted next to the aerogel and its tilting angle is 45° with respect to the bending orbital plane.

EXPERIMANTAL SETUP

The Cherenkov radiator was installed in the beam transport line from the linac to the FEL system as shown in Figure 3. The distance between the radiator and the bending magnet is 320 mm and the dispersion function η at this position is 0.4 m. Since the effective view width of the aerogel is 40 mm, the energy acceptance and the energy resolution on the radiator are estimated to be 10 % and 0.25 % / mm, respectively.

The light generated by the aerogel in the linac room is carried in the atmosphere on the optical transport system of about 15 m, and measured with a streak camera in the measurement room. The streak camera converts an optical image on the input slit to a streak image with spatial information displayed on the horizontal axis and time on the vertical axis. We are using the streak camera C5680-11 (Hamamatsu Photonics), which has the temporal resolution of 1.57 ps with the fast speed sweep unit C5676. The effective area of the streak camera is 11(H) x 8.25(V) mm^2 at screen. So we have to adjust the aerogel image into the area using an optical transport system. Since it had not completed the optical transport system, we used temporary setup consist of the existing mirrors. As a result, the multiplication factor and the transportation efficiency of the transport system were not optimized, and the horizontal size on the aerogel subtended from the streak camera is limited only to 4.4 mm, which is corresponding to the energy acceptance of 1.1 %. Thus we could acquire not the entire longitudinal phase-space image but the energy sliced one. Therefore, the longitudinal phase-space image was reconstructed by uniting the sliced images which were acquired by sweeping the magnetic field of the bending.

EXPERIMANTAL RESULTS

Figure 4 shows the energy spectrum of the single bunch electron beam which was used for the experiment. The electron bunch was accelerated by the 1.3 GHz L-band electron linac which has a three stages sub-harmonic buncher (SHB) system composed of two 108 MHz and one 216 MHz cavities. Due to the SHB system, it becomes possible the production of the high current electron bunch which has a typical charge of 30 nC. On the other hand, it is expected that the electron bunch has a more complex correlation between longitudinal electron positions and their energies.

Figure 5 shows the longitudinal phase-space profiles reconstructed from several images acquired while changing the magnet current at intervals of 0.05 or 0.1 A for three different accelerating phases. The profile images in the figure have temporal information as the horizontal

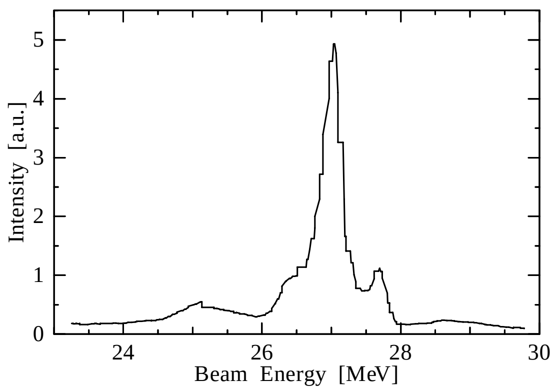

Figure 4: Energy spectrum of the single bunch electron beam with the peak energy of 27 MeV and the total charge of 30 nC.

axis and energy one as the vertical axis. The left side indicates the head in the electron bunch. The energy spectrum as shown in Figure 4 corresponds to the profile (b) in Figure 5. The profiles (a) and (c) in the figure were measured at the accelerating phase shifted by -10° and +10° from the phase of (b), respectively. In the profiles (a) and (c), there are tendencies to a monotonous increase or decrease energy from the head to the tail. However, when seeing more in detail, it can be seen that the electrons of different energy exist on the same phase. Especially in the profile (b), electrons have a more complicated distribution in the longitudinal phase-space compared with a sinusoidal wave. Since the wake field induced by the electron bunch is superimposed to the accelerating fields, the electrons experience the distorted field. It will be possible qualitatively to explain these profiles using the wake field.

SUMMARY

In order to measure the longitudinal phase-space profile of the electron beam, we are developing the measurement system consisted of the Cherenkov radiator, the bending magnet and the streak camera. The Cherenkov radiator with the aerogel was installed in the beam transport. We measured the energy sliced longitudinal phase-space images using temporary optical transport setup and reconstructed the preliminary longitudinal phase-space profile from the sliced images.

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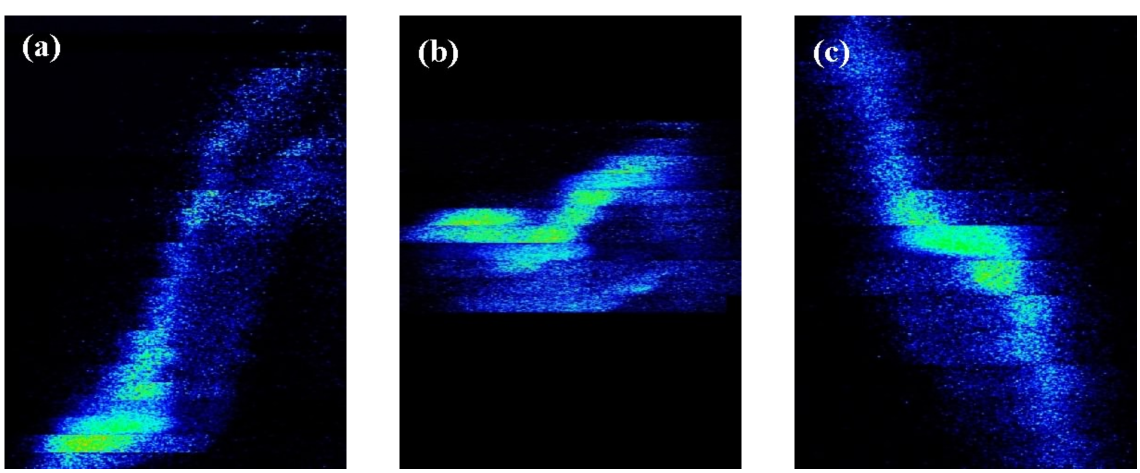

Figure 5: Reconstructed longitudinal phase-space profiles of the single bunch electron beam for three different accelerating phases. The profile images have temporal information as the horizontal axis (150 ps / full scale) and energy one as the vertical (9.6 % or 2.6 MeV / full scale). The left side indicates the head in the electron bunch. Accelerating phases of the bunch center are estimated to (a) -20° , (b) -10° and (c) 0° from the rf crest, respectively.