DEVELOPMENT OF THE LONGITUDINAL PHASE-SPACE MONITOR FOR THE L-BAND ELECTRON LINAC AT ISIR, OSAKA UNIVERSITY*

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Abstract

In order to measure the longitudinal phase-space profile of the high-brightness electron beam, we are developing the measurement system consisted of a profile monitor, a bending magnet and a streak camera. Instead of an optical transition radiation (OTR) monitor as previously considered, a Cherenkov radiator with a hydrophobic silica aerogel is used as a profile monitor. Due to the physical limitation at the installation location, we designed a simple radiator supported with a metallic mirror. The Cherenkov radiator has been designed, and it is in the process of production.

INTRODUCTION

The performance of the self-amplified spontaneous emission free-electron laser (SASE-FEL) strongly depends on beam parameters, such as a longitudinal beam profile, bunch charge, the transverse emittance and an energy profile. A correlation between longitudinal positions of electrons in a bunch and their energies has a crucial effect on the temporal evolution of the optical pulse of SASE. 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 [6-8]. 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 report, we introduce the design of the longitudinal phase-space monitor using a Silica aerogel Cherenkov radiator and the system layout.

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PROPERTIES OF AEROGEL AND ITS CHERENKOV RADIATION

Aerogel is a low-density light-weight solid material produced by replacing the liquid component in the gel with gas. Silica aerogel, which is a silica-based substance, is the most common type of aerogel and has extremely light weight, extraordinary thermal insulation abilities, etc as a feature. We use a hydrophobic silica aerogel manufactured by Matsushita Electric Works, Ltd. (MEW). They supply several types of aerogel as shown in Table 1. In high energy particle physics, these aerogels are also used as radiators in Cherenkov detectors of the Belle detector system at KEKB.

Table 1. Characteristics of hydrophobic silica aerogels.

Aerogel type	SP-15	SP-30	SP-50
index of refraction	1.015	1.03	1.05
density (g/cm3)	0.06	0.11	0.19

Cherenkov radiation is emitted when a charged particle passes through a medium at a velocity greater than the speed of light in that medium. 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:

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

Figure 1 shows the emission angle of Cherenkov radiation in the aerogel radiator versus the electron energy. Above the electron energy of 10 MeV, the emission angle is almost constant. However, the angle is too large to gather all rays of light. The number of photons N_{CR} radiated as Cherenkov radiation with wavelengths between λ_1 and λ_2 per a distance d along the path of the electrons is represented as follows:

$$\begin{aligned} N_{CR} &= 2\pi\alpha d\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\left(1 - \frac{1}{\beta^2 n^2}\right), \\ &= 2\pi\alpha d\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\sin^2\theta_{CR} \end{aligned} \tag{2}$$

where α is the fine structure constant. Figure 2 shows the number of photons emitted from the aerogel with different indices of refraction. In this case, the wavelength region is assumed to be equal to the sensitivity region of the streak camera (400 ~ 800 nm). The photon yield of Cherenkov

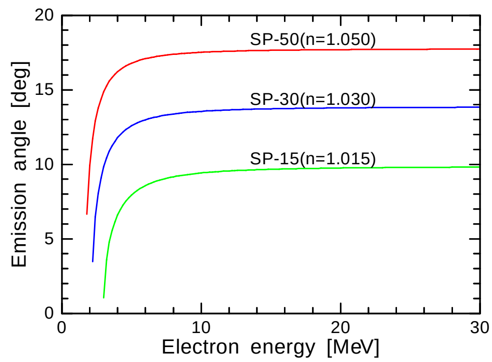

Figure 1: The emission angle of Cherenkov radiation in the aerogels with different indices of refraction.

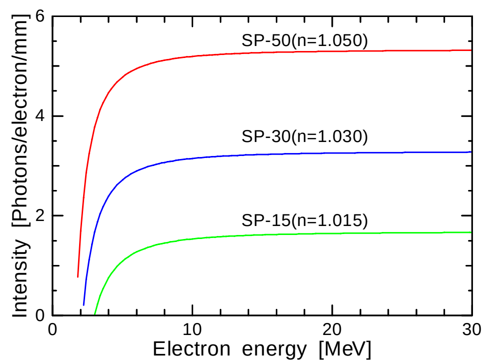

Figure 2: The number of photons as Cherenkov radiation per electron per 1 mm distance emitted from the aerogels with different indices of refraction.

radiation per incident electron in the visible region is larger than that of OTR by two orders of magnitude.

DESIGN OF CHERENKOV RADIATOR

We intend to install the Cherenkov radiator in the beam transport line form the linac to the FEL system as shown in Figure 3. Due to the physical limitation at the installation location, we can not bring a complicated mechanism into a vacuum. We designed a simple radiator supported with a metallic mirror as shown in Figure 4. In this radiator, we use a thin aerogel with a dimension of 45 x 30 mm^2 and a thickness of 1.5 mm manufactured by MEW as a trial. For this thickness, they can produce the aerogels only with the refractive indices of 1.03 (SP-30) and 1.05 (SP-50). Since the aerogels SP-30 are fragile and almost half of them were cracked, we decide to use the aerogels SP-50. Figure 5 shows the example of the manufactured aerogels.

Cherenkov radiation in the aerogel SP-50 is emitted in a cone having a subtended angle of 35.5°. 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.

ESTIMATION OF PHOTON YIELD

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 the streak camera by mirrors. The light accepted by the first concave mirror is estimated approximately to 10 % of the total radiation. In order to eliminate broadening of the pulse width of light in the air, an interference filter will be used. Assuming that the filter has a wavelength range from 400 nm to 410 nm and that its transmittance is 40 %, the photon yield on the entrance slit of the streak camera is expected to 0.027 photons per electron. The number of electrons in a single bunch accelerated by the L-band linac is typically about 2 x 10^{11}. The net number of photons produced by one bunch is expected to be 5.4 x 10^9 on the slit.

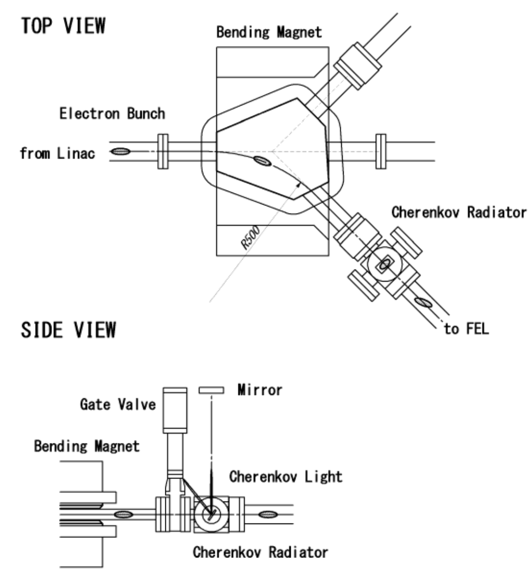

Figure 3: Configuration of the Cherenkov radiator.

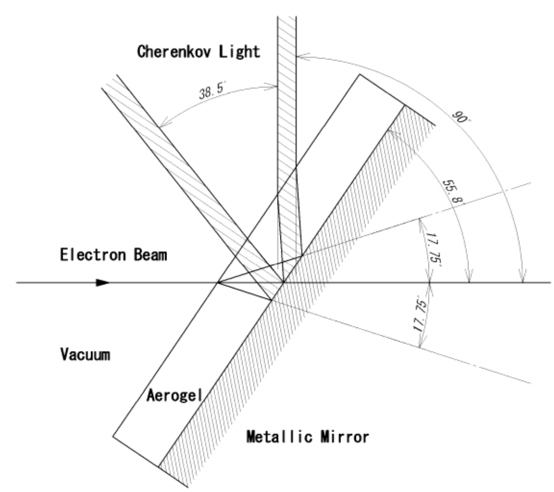

Figure 4: Schematic design of the Cherenkov radiator.

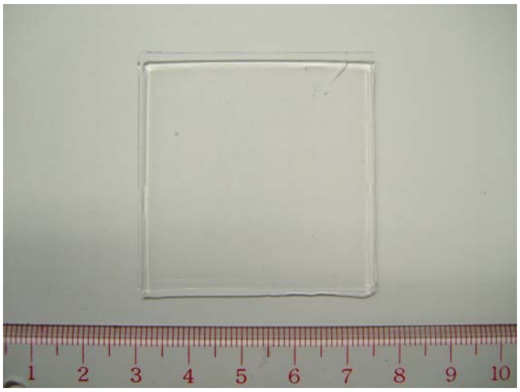

Figure 5: A thin hydrophobic silica aerogel used as a Cherenkov radiator with a thickness of 1.5 mm and the refractive index of 1.05.

In the meanwhile, the view size of a CCD camera used in the streak camera is 10(H) x 9.5(V) mm^2. Since the ratio of the entrance lens of the streak camera is 1/3, an acceptable horizontal width is approximately 30 mm on the entrance slit. If the effective horizontal size of the aerogel without a folder (40 mm) is matched to this size, the aerogel screen size is projected to 30 x 10.5 mm^2 on the entrance slit. If the photons spread on this area uniformly, the density of photon is 1.7 x 10^7 photons / mm^2. This density exceeds the detection limit of the streak camera on the entrance slit, 5,000 photons / mm^2. A streak image of Cherenkov radiation will be obtained using this system.

EVALUATION OF ENERGY RESOLUTION

The Cherenkov radiator is placed at a position 320 mm downstream from the first bending magnet as shown in Figure 3. Since dispersion function η is 0.4 m at the position of the Cherenkov radiator, the energy acceptance of the measurement system and the energy resolution on the radiator are estimated to be 10 % and 0.25 % / mm, respectively. However, the beam image is considered to be broadened due to the thickness of the Aerogel. In order to evaluate this broadening, we plan to measure the beam profile with a fluorescence ceramic screen with a thickness of 0.1 mm at the same location. Figures 6 shows a drawing of the screen folder mounted with both of the ceramic screen and the Cherenkov radiator, and Figure 7 shows the photograph of its drive assembly with a two-staged stroke. There is a wire scanner profile monitor at the straight beam line of the L-band linac, and we have already evaluated the broadening of the profile size obtained by the ceramic screen with the wire scanner. Calibrating the broadening of that due to the aerogel with the ceramic screen, the energy resolution will be evaluated precisely.

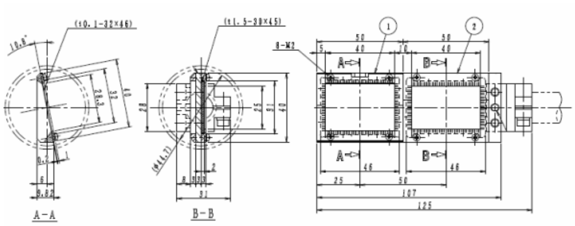

Figure 6: Screen folder mounted with both of a ceramic screen and a Cherenkov radiator. (1) The first screen is a profile monitor with a fluorescence ceramic screen with a thickness of 0.1 mm and it is tilted vertically by an angle of 45° with respect to the bending orbital plane. (2) The second screen is the aerogel radiator and it is tilted of 55.8°.

Figure 7: The drive assembly of the Cherenkov radiator with a two-staged stroke. The first stage is a profile monitor with a fluorescence ceramic screen, and the second stage is the Cherenkov radiator with the aerogel.

SUMMARY

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 has been designed, and it is in the process of production.

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