

Beam Monitor Utilizing Transition Radiation

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Abstract

Beam monitors utilizing electromagnetic waves, especially visible light radiated by charged particles, have several excellent features for beam diagnostics in accelerators: they are essentially free from environmental electromagnetic noise and are characterized by a high-speed time response. A beam monitor based on transition radiation is one of the most promising monitors concerning positions, sizes, emittance, energy and time structures of bunches for high-intensity, short-pulse beams. We started to develop beam monitors utilizing transition radiation for the beam diagnostics of high-intensity electron beams. Bunch-length measurements were performed at the KEK 2.5-GeV linac with this monitor and a streak-camera system.

I. INTRODUCTION

Precise measurements of the beam parameters of an intense beam are indispensable for the stable operation of future accelerators. For instance, in the linac for the B-factory project proposed at KEK [1], it is required to accelerate an intense single-bunched beam of about 10 nC to a positron production target without any degradation of the beam quality; the beam-emittance growth due to a transverse-wake instability must be suppressed by precisely adjusting the beam position to the center of accelerating structures. In this case, beam-position monitors play an essential role. Bunch-length measurements become crucial for estimating the short-range wake fields, since their strength, especially the longitudinal type, strongly depends on the bunch shape. In any case, all of the beam parameters should be measured and evaluated not only precisely, but also reliably.

Beam monitors utilizing electromagnetic waves, especially visible light radiated by charged particles, have several excellent features for beam diagnostics in accelerators: they are essentially free from environmental electromagnetic noise and are characterized by a high-speed time response. Cherenkov radiation as well as synchrotron radiation is commonly used as input light for a beam-monitoring system; for example, the bunch length is measured at a good time resolution of less than several picoseconds by guiding the Cherenkov radiation into a streak camera. The handling of both systems, however, is generally not simple; in the case of

Cherenkov radiation, some special material or gas must be inserted into a beam line to generate radiation; there are also some problems regarding the radiation angles and the threshold energy of the radiation. Moreover, the optical system, for instance that which leads the light to the streak camera, may be complex, since the radiation source is essentially not point-like.

A beam monitor based on transition radiation [2-5] is one of the most promising monitors concerning positions, sizes, emittance, energy, and time structures of bunches for high-intensity, short-pulse beams. It has been noticed that transition radiation is generated from a point-like source under certain conditions, which makes it easier to arrange an optical system.

In this connection, we started to develop beam monitors utilizing transition radiation for the beam diagnostics of high-intensity electron beams. The fundamental concepts of the monitor are given and preliminary results concerning bunch-length measurements using this monitor with a streak camera is presented.

II. TRANSITION-RADIATION BEAM MONITOR

A. Principles

Transition radiation occurs during the uniform motion of a charged particle in a spatially inhomogeneous medium: for instance, when passing from one medium to another. For beam diagnostics, we utilize the radiation emitted from a vacuum-metal boundary; in practice, a thin metal foil is inserted into the beam line with an oblique angle to the beam direction of motion (Fig. 1). The radiation emitted by the metal surface is characterized by two features: a sharp angular directivity for relativistic particles, and a formation zone. The angular distribution of the radiated energy in a unit angular frequency (ω) is expressed as [2]

$$W(\omega, \theta) = \frac{e^2 \beta^2}{\pi^2 c} \frac{\sin^2 \theta}{(1 - \beta^2 \cos^2 \theta)^2},$$

where e is the electron charge, β the velocity of the charged particle divided by the velocity of light (c), and θ the angle of radiation (Fig. 1). The formation zone for radiation with a wavelength of $\lambda = 2\pi c / \omega$ is determined by the cylinder around the beam axis at a depth of d and a radius of ρ :

$$d = \gamma^2 \frac{\lambda}{2\pi} \quad (\text{in the vacuum side})$$

and

$$\rho = \gamma \frac{\lambda}{2\pi}.$$

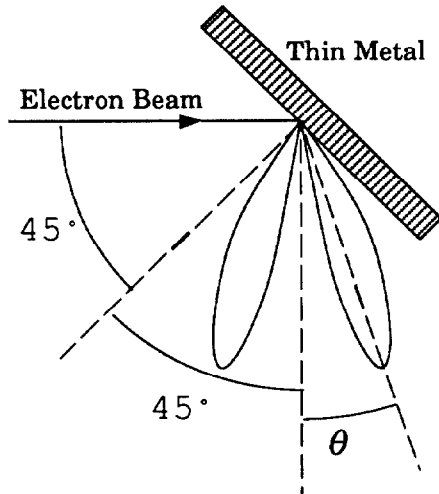


Fig. 1 Usual configuration of transition-radiation beam monitors. The radiation has sharp directivity.

Figure 2 shows the angular directivity pattern of transition radiation, indicating a narrow angular distribution with a characteristic angle of $\theta = 1/\gamma$ for two peaks, which allows easy installation of the light-guiding optics. The formation zone determines the fundamental resolution as a beam monitor; the formation radius provides position/size resolution for beam-profile monitors. The relativistic Lorentz factor (γ) appeared in the formation zone size, indicating the effectiveness of utilizing transition radiation in beam monitors at relatively low energy.

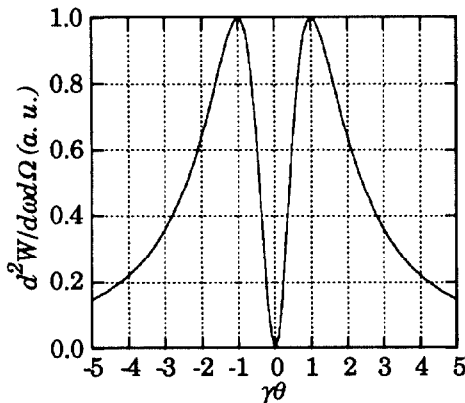


Fig. 2 Directivity pattern of transition radiation. It has two maximums at angles of $\theta = \pm 1/\gamma$.

B. Experimental

The experimental configuration for a transition-radiation monitor is shown in Fig. 3. A thin, polished mirror of stainless steel with a thickness of 2 mm is inserted into the beam line at the end of the first two accelerating guides after the bunching system of the KEK 2.5-GeV linac [6]. An electron beam with a peak current of 4 A and a pulse width of 15 ns hits the metal at an energy of about 50 MeV. The visible light emitted in a small angle from the thin metal is transported through an achromatic optical system to a CCD camera for beam-profile observations, as well as to the streak camera for bunch-length measurements. For the bunch-length measurements, the beam spot was adjusted to be about 3-4 mm in diameter, so as to optimize the light flux; at the input of the streak-camera system with a slit width of 30 μm , the photon number per bunch amounts to about 10^5 , which is measurable by a streak-camera system of Hamamatsu Photonics Ltd., Japan, with a time resolution of 2 ps for a single-shot measurement.

The alignment of the light-guiding system from the metal to the input of the streak camera was made by using a He-Ne laser placed at the other side of the light-extraction window (Fig. 3). The position and direction of the laser light was determined so that it simulated the transition radiation emitted at the metal surface.

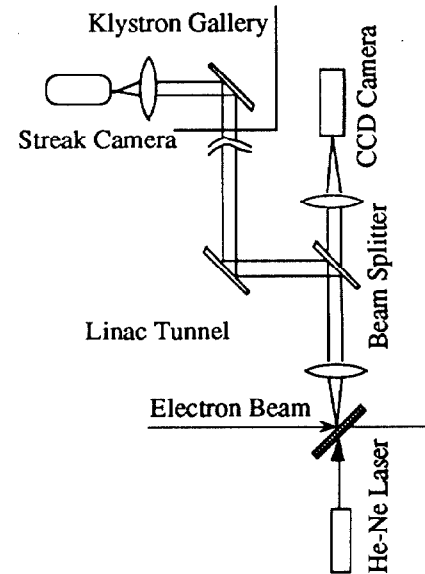
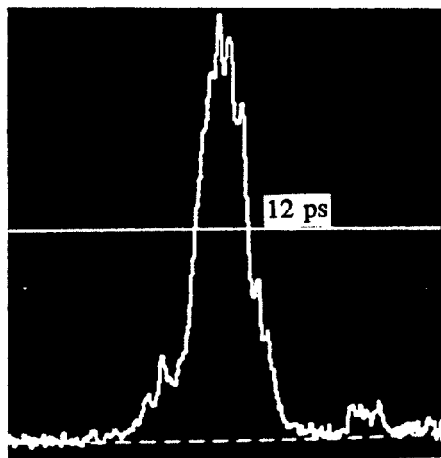


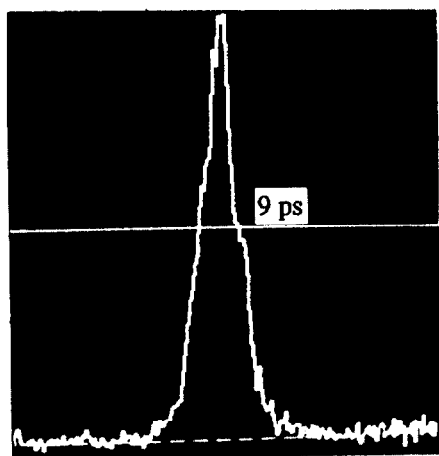
Fig. 3 Light-guiding system for streak camera.

The bunch shape for one of the bunches was observed with this system (Fig. 4). The bunch length was measured in two cases in order to demonstrate the system performance; the upper photograph of Fig. 4 indicates the bunch shape with a

width (FWHM) of about 12 ps when the bunching strength was set to a modest value; the lower shows a bunch length of about 9 ps under good bunching conditions.



(a)



(b)

Fig.4 Demonstration of bunch-shape measurements by a transition-radiation monitor at the end of the first accelerating guides after the bunching section. (a) The prebuncher power is not optimized, and (b) optimized. The beam energy is about 50 MeV and the charge/bunch amounts to about 1 nC.

III. CONCLUSIONS AND DISCUSSIONS

A transition-radiation monitor has been developed for precise beam diagnostics of an intense beam. Among several excellent features of this monitor, we first applied its fast time response to bunch-length measurements. The preliminary results in the bunch-length measurement using transition radiation as a light source for a streak-camera system seems to indicate good performance of the monitor. Further elaboration as the bunch monitor and applications to the beam

position/size monitor for precise emittance measurements [7] will be made in the near future.

The fundamental resolution of the transition-radiation monitors is estimated by evaluating the formation zone mentioned above; in optical wavelengths (e.g. 500 nm) the depth of the formation zone for a beam energy of 50 MeV becomes about 0.8 mm, while the zone radius is about 8 μm , giving the position/size resolution.

The light-guiding system also causes some sort of aberration, which degrades the time resolution. A rough estimation gives 1-2 ps of time resolution in our system. We plan to improve the optical system by selecting a narrow band of visible light so as to decrease the chromaticity as well as to utilize single-mode fibers for easy light guiding.

IV. ACKNOWLEDGMENT

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V. REFERENCES

- [1] B-Factory Accelerator Task Force, "Accelerator design of the KEK B-Factory", edited by S. Kurokawa, K. Satoh and E. Kikutani, February, 1991, KEK Report 90-24.
- [2] V. L. Ginzburg and V. N. Tsytovich, "Several problems of the theory of transition radiation and transition scattering", *Physics Reports*, **49**, 1 (1979).
- [3] L. Wartski, S. Roland, J. Lasalle, M. Bolore and G. Filippi, "Interference phenomenon in optical transition radiation and its application to particle beam diagnostics and multiple-scattering measurements", *J. Appl. Phys.* **46**, 3644 (1975).
- [4] M. Jablonka, J. Leroy, X. Hanus and L. Wartski, "Beam diagnostic using transition radiation produced by a 100 MeV electron beam", DPhN Saclay 91-32.
- [5] D. W. Rule, "Transition radiation diagnostics for intense charged particle beams", *Nucl. Instrum. Methods B24/25*, 901 (1987).
- [6] S. Ohsawa, I. Abe, S. Anami, J. -Y. Choi, A. Enomoto, K. Furukawa, H. Hanaki, K. Kakiyama, N. Kamikubota, T. Kamitani, H. Kobayashi, Y. Ogawa, T. Oogoe, I. Sato, T. Suwada, Y. Yamazaki, M. Yokota and A. Asami, "New pre-injector of the KEK 2.5-GeV linac and its performance", these proceedings.
- [7] R. Chehab, M. Taurigna and G. Bienvenu, "Beam emittance determination using optical transition radiation", *The Third European Particle Accelerator Conference*, Berlin, Germany, March 24-28, 1992, pp.1139-1141.