Spectrum of Coherent Synchrotron Radiation

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ABSTRACT

The complete spectrum of coherent synchrotron radiation were measured in the wavelengths of 0.1 ~ 2.0 mm and a bunch shape was estimated by the Fourier analysis for this spectrum. This agrees with the result of simulation for the bunching process in the injector of the accelerator. The interferential effects between radiation which were emitted by the different bunches were observed by an interferometer. It was shown that every radiation had the same phase when it was emitted by a bunch.

1. Introduction

In January, 1989 the coherence effects in synchrotron radiation (SR) were observed for the first time at Tohoku 300 MeV Linac[1]. It had a continuous spectrum and its intensity was more than 10^6 times as great as that of ordinary SR at wavelengths $\lambda = 0.33 \sim 2.0$ mm. This enhancement factor was almost as same order as N, the bunch population, and the radiation intensity was proportional to N^2. The spectrum of coherent SR was dominated by the bunch length of the electron beam[2] as expected by the classical theory. The radiation was mainly polarized in the orbital plane.

In our recent experiment we measured the complete spectrum at $\lambda = 0.1 \sim 2.0$ mm using a special far infrared spectrometer for coherent SR. We will present these results and discuss about the relation among a bunch shape and spectrum. The interferential effects among the radiations from different bunches were observed by an interferometer to show a direct evidence of coherent radiation.

2. Spectrum of coherent SR

A spectrometer was prepared to measure coherent SR with special care to avoid the stray light in longer wavelengths. Combining gratings with band-pass filters in this spectrometer and using a Si bolometer as a detector, we could measure the radiation spectrum over $\lambda = 0.1 \sim 2.0$ mm. During the measurement the radiation fluctuated because of the instability of electron beam intensity. In order to correct the effect of this fluctuation, we used a radiation monitor, which is another set of a spectrometer and a detector, at fixed wavelength.

As is shown in Fig. 1, the complete SR spectrum was obtained in the wavelength region of 0.15 ~ 2.0 mm. In this experiment the beam energy was 150 MeV and bending radius was 2.44 m. The radiation intensity is normalized for an average beam current of 1 μA, which corresponds to $N = 3.6 \times 10^6$. As the intensity of incoherent SR is 6×10^6 [photons/sec/mrad/1% BW] at 1 μA and $\lambda = 1$ mm, the enhancement factor at $\lambda = 1$ is 3×10^6 ($= 2 \times 10^{13}/6 \times 10^6$), which is almost same value as N. It has the continuous spectrum in these wavelengths and its intensity decreases rapidly for $\lambda \leq 0.5$ mm. For $\lambda < 0.15$ mm the spectrum was not able to measure because of the insufficient radiation intensity.

According to the classical electromagnetic theory[4], the intensity of coherent SR $I_{coh}(\omega)$ at an angular frequency ω is given by

$$I_{coh}(\omega) = I_{incoh}(\omega)\{1 + (N-1)F(\omega)\} \tag{1}$$

$$F(\omega) = \left| \int e^{j\omega \mathbf{n}\cdot\mathbf{r}/c} S(\mathbf{r}) d\mathbf{r} \right|^2 \tag{2}$$

where I_{incoh} is the intensity of incoherent SR derived by Schwinger[5], N and $S(\mathbf{r})$ the number and distribution of electrons in a bunch, $\mathbf{n}$ a unit vector toward the observing point and $F(\omega)$ a bunch form factor. We estimated a longitudinal bunch shape (Fig. 2) by the inverse Fourier transform of $I_{coh}(\omega)$. In this result the bunch length was 0.3 mm at FWHM.

We simulated the bunching process in the injector section and estimated the bunch shape[6]. The bunch lengths of 0.2 $\sim$ 0.5 mm were obtained at an energy of 10 MeV. Though we did not take into account a space charge effect nor did we reproduce completely the experimental conditions by the accelerating parameters in this calculation, this bunch length agrees reasonably with that obtained from the SR spectrum.

3. Interferential effect

A Martin-Puplett-type interferometer (Fig. 3) was prepared to obtain an interferogram between two radiations which are emitted by different bunches. Radiation which was emitted by a bunch was delayed by $DeltaL$, the optical path difference, and interfered with another radiation which was emitted by the next bunch.

Two interference patterns were observed in the interferogram as shown in Fig. 4. The first one at $\Delta L = 0$ mm is an autocorrelation, which corresponds to the interference with itself, and the second one at $\Delta L = 105$ mm is cross-correlation, which corresponds to the mutual interference with the radiation from next neighbor bunch. The optical path difference of the second interference is located at the completely same optical path difference as the distance between the bunches, determined by the wavelength of an accelerating RF frequency of 2856 MHz. The shape of the first interference pattern is congruous with the second one. That is, the first radiation emitted by a bunch has the same amplitude and phase as the second one by the next bunch. This is a direct evidence that radiation observed is coherent.

4. Conclusion

Two additional important results were obtained by the recent experiments. 1) The bunch length which was calculated by Fourier analysis of the radiation spectrum agreed with the result of the simulation of the bunching process. 2) The coherent property of radiation was directly observed by the interferometer.

As an application example, the physical experiment of the superionic conductor has already been started in Tohoku 300 MeV Linac. We are preparing the equipments for the routine application experiments.

References

1) T. Nakazato, M. Oyamada, N. Niimura, S. Urasawa, O. Konno, A. Kagaya, R. Kato, T. Kamiyama, Y. Torizuka, T. Nanba, Y. Kondo, Y. Shibata, K. Ishi, T. Ohsaka and M. Ikezawa, Phys. Rev. Lett. **63** (1989) 1245.
2) T. Nakazato, M. Oyamada, N. Niimura, S. Urasawa, R. Kato, Y. Shibata, K. Ishi, T. Ohsaka, T. Takahashi, H. Mishiro, M. Ikezawa, Y. Kondo, T. Nanba and Y. Torizuka, Particle Accelerators **33** (1990) 141.
3) K. Ishi, Y. Shibata, T. Takahashi, H. Mishiro, T. Tsutaya, T. Ohsaka, M. Ikezawa, Y. Kondo, M. Oyamada, N. Niimura, S. Urasawa, T. Nakazato and R. Kato, Research Report of Laboratory of Nuclear Science, Tohoku University, **23**, (1990) 131.
4) G. P. Williams, C. J. Hirschmugl, E. M. Kneedler, P. Z. Takacs, M. Shleifer, Y. J. Chabal and F. M. Hoffmann, Phys. Rev. Lett. **62**, (1989) 261.
5) J. Schwinger, Phys. Rev. **75** (1982) 1912.
6) Y. Shibasaki, M. Oyamada, S. Urasawa, T. Nakazato, A. Kurihara, S. Takahashi, R. Kato, S. Niwano, T. Eguchi and N. Matsumoto, presented at this meeting.

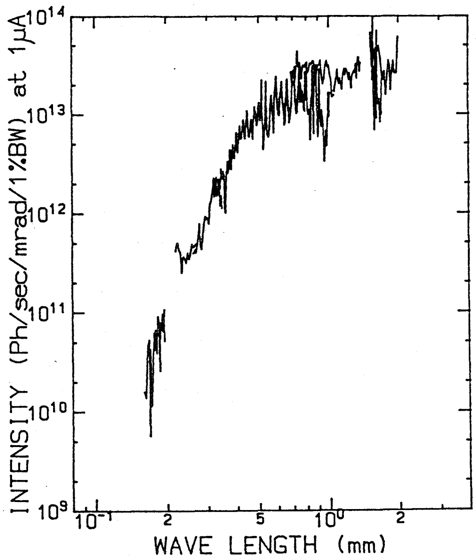

Fig. 1. Ovserved spectrum of coherent SR.

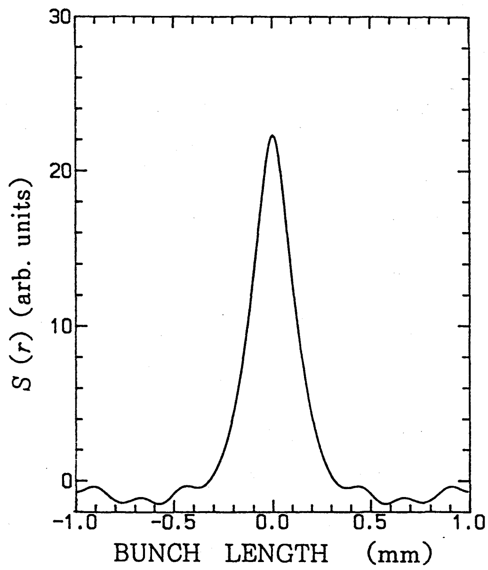

Fig. 2. Bunch shape calculated from the SR spectrum by the Fourier transform analysis.

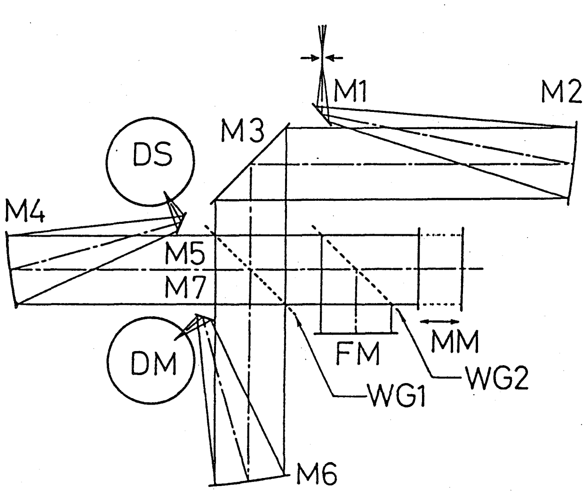

Fig. 3. Interferometoer to measure the interference effect between bunches.

M1, M3, M5, M7	:	plane mirrors
M2, M4, M6	:	collimators
WG1, WG2	:	wire grids
FM	:	fixed mirror
MM	:	moving mirror
DS	:	detector for signal
DM	:	detector for monitor

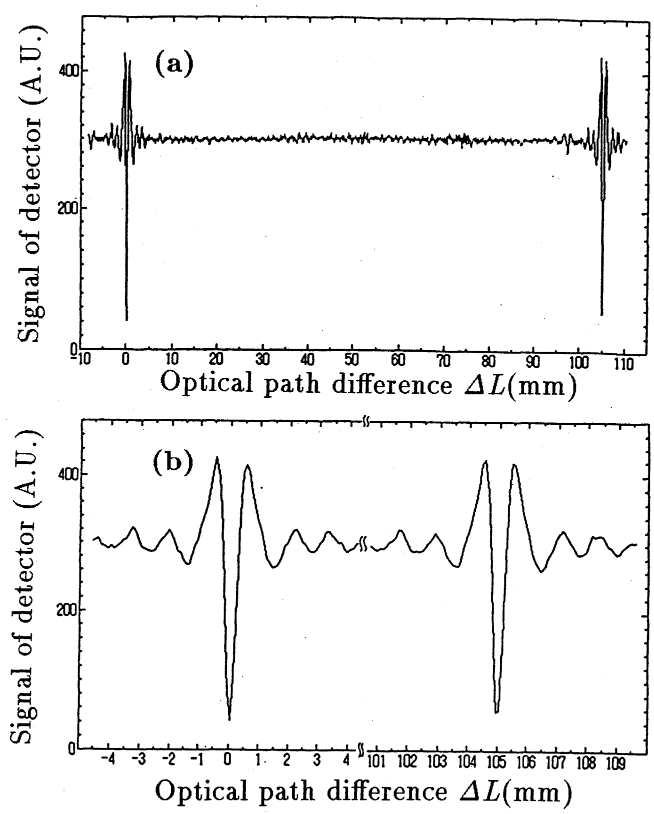

Fig. 4. Interferogram of Coherent SR.
(a) Full picture.
(b) Enlarged detail around ΔL=0 mm and ΔL=105 mm.