COHERENT SYNCHROTRON RADIATION BURST FROM ELECTRON STORAGE RING UNDER EXTERNAL RF MODULATION

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Abstract

We quantitatively investigated the time structure of coherent synchrotron radiation (CSR) burst to find out how unstable it is. When the rf phase was modulated with 2*fs* (twice of the synchrotron oscillation frequency), the burst structure was modulated with 2*fs* and the fluctuation of radiation power was reduced.

INTRODUCTION

It is known that a high peak current beam in electron storage ring emits burst of coherent synchrotron radiation (CSR) in THz region [1-7]. In comparison with the other methods to produce CSR in electron storage ring, this method supplies higher power and the CSR is easy to be obtained with no special expense. The high peak current is normally obtained in a single bunch or a few bunch operations. Despite these merits of CSR burst, it is not used for experiments. This is because the origin of the CSR burst is a fine time structure in the bunch due to longitudinal beam instabilities, therefore, the burst is not stable. We investigated the time structure or fluctuation of the CSR burst to know how unstable the burst is. We hope that the bursts would have an application with an appropriate time averaging.

The burst is qualitatively understood as so-called saw-teeth instability. The time structure in a bunch was produced by a beam induced field (wake field) or CSR itself. The instability (oscillation condition) has a threshold peak current, which depends on the energy spread and others. When the beam condition is above the threshold, a fine time structure grows in a bunch and emits CSR. At the same time this enlarges the energy spread, and stops the instability and CSR. After the burst the radiation damping gradually reduces the energy spread and bunch length until the next burst starts.

We have already reported the time structure of CSR with the beam current dependence in normal condition and bunch compressed conditions, reducing the momentum compaction factor (α) or raising the rf acceleration voltage (V_{rf}) [8]. The measurements of CSR from one bunch showed that with an average period of 10 ms (comparable with the longitudinal damping time, 12 ms) the fluctuation of averaged power was about 10%. The fluctuation ratio had small dependence on beam charge, rf acceleration voltage and momentum compaction factor. The successive bursts had a correlation because the beam had a memory of former bursts. This worked to reduce the fluctuation in long period.

This article reports CSR under the rf phase modulation, where a bunch in one rf bucket is separated to three [9]. In our case, the three bunches synchrotron oscillate in an rf bucket.

Beside the easiness of production, there are two key accelerator techniques of operation for users. The first is an accurate bucket selection in the injection process, which keeps the high current single bunch. The second is the top-up operation, which roughly keeps the constant beam current. This is important because the high peak current beam has a short Touchek lifetime. These techniques are not common but to be introduced at many existing facilities and will be standards of synchrotron radiation ring.

MEASUREMENT SETUP

Storage Ring

The electron storage ring for the measurement was NewSUBARU (NS), 1.5 GeV synchrotron radiation ring at the SPring-8 site. It was operated with top-up mode at 1.0 GeV during this measurement. The maximum stored beam current at the single bunch operation is 70 mA for the circumference of 119 m. Normally the rf acceleration voltage (V_{RF}) at 1 GeV is 100 kV and the linear momentum compaction factor (α) is 0.0012. The un-loaded synchrotron oscillation period is 0.2 ms.

In order to give modulations to the CSR burst, we applied a modulation to the phase of the rf acceleration field, with frequency of twice of the synchrotron oscillation frequency (2*fs*=10.2kHz).

CSR Radiation Detector

We used commercially available Schottky diode detector (WR5.1ZBD; Virginia Diode Inc.). It was sensitive to a radiation of 0.14 - 0.22 THz, at just above the cut-off of the light extraction port. The signal from the diode was amplified (17dB; 10kHz - 1GHz band) and recorded by a digital oscilloscope (10Gs/s; 2GHz).

With a single shot, the signal for 10 ms (=25250 revolutions) was recorded. The pulse width was 1.2 ns FWHM, which was much longer than the electron bunch length. The pulse area for each revolution was calculated at off-line analysis and applied non-linearity correction. The results gave relative radiation power for every

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revolution from the same bunch. Fig. 1 shows examples of the results. The frequency (=number of pulses) distribution of pulses for CSR power was obtained from measurements of 10 or 6 shots.

RESULTS

Previous Measurement

In the previous study, sets of measurements took place at stored beam current (I) of 5 mA, 10 mA, 20 mA, 40 mA, and 60 mA with normal V_{RF} and α. The current dependence of the time structure showed typical behavior, which has been observed at other facilities. The radiation burst was observed at above the threshold current (about 3 mA at normal condition of NS). The plot of the averaged radiation power against the beam current showed the dependence between the linear and the parabolic, which was also observed at other facilities.

At lower current of 5 mA and 10 mA, we observed a quasi-periodic burst. The integrated power in one burst had weak correlation with the successive time interval to the next burst. This was reasonable that a stronger burst ended with larger energy spread and then the beam required longer time for dumping to the threshold level. With higher beam current, the number of bursts in 10 ms increased and the burst width became narrower. At above 20 mA, weak burst appeared between strong bursts and the quasi-periodic structure disappeared into a chaotic burst.

We calculated the fluctuation of time averaged CSR power. σ of the averaged powers with fixed period, normalized with the total average of 10 shots, was plotted against the period length (Fig. 2). When we took the averaging period of 10ms, the fluctuation of the integrated power was about 10%. It was not strange that the fluctuation decreases rapidly with the period length at the length close to the time interval for quasi-periodic burst.
Two other parameters of our interest were V_{RF} and α. They are often used to compress the bunch and reduce the threshold current. We investigated the effect of these parameters on the fluctuation of the CSR burst. Both of them raised the radiation power for the same beam charge and gave slight improvement of the fluctuation.

CSR burst under RF modulation

The third figure of Fig. 1 shows the typical time structures of CSR burst under the modulation. The burst timing was roughly synchronized with the modulation signal. Fig. 3 shows the typical bunch structure and the burst in a modulation period. The bursts took place after about 1/4 of the modulation period. Fig. 2 shows the fluctuation of the averaged power. The fluctuation was improved, but not so much as we hoped.

Fig. 4 shows the jittering of the bunch crossing timing (bright points in Fig. 3(a)) and the burst timing (average of a pulse like that in Fig. 3(b)). The jittering of the averaged radiation timing to the phase of the external modulation signal was what we did not want. At least one of the sources of it was the shift of the bunch crossing timing.

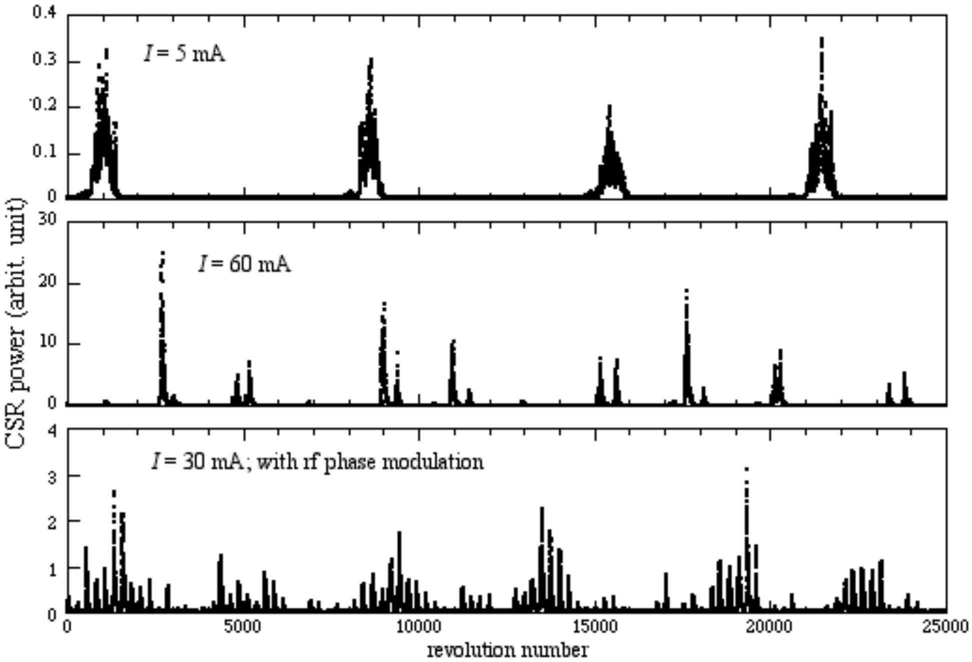

Figure 1: Examples of observed time structure of CSR burst in 10ms with normal ring parameters. The above two are the typical quasi-periodic burst at low current and the chaotic burst at higher current. The bottom trace shows the structure under the rf phase modulation (the modulation period is roughly 250 revolutions).

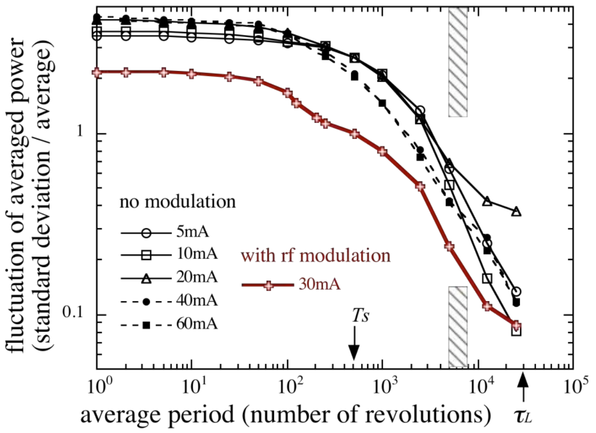

Figure 2: Fluctuation of time-averaged CSR power. The arrows with *Ts* and τ_L indicate the synchrotron oscillation period and the longitudinal damping time, respectively. The shaded rectangles show the interval of the quasi-periodic burst shown in Fig.1.

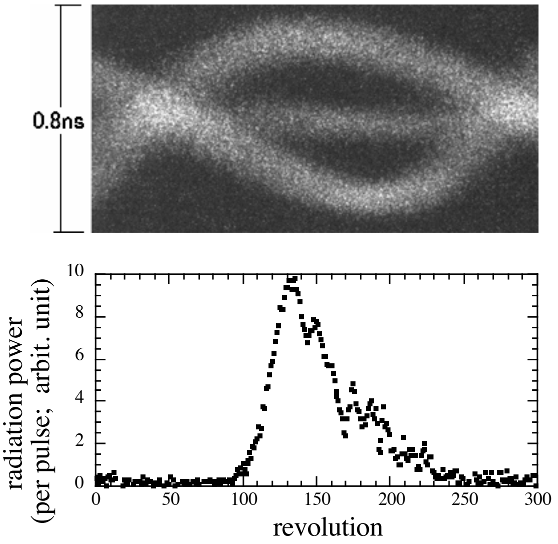

Figure 3: Three bunches in a bucket (above image) and the CSR timing (below). The vertical axis of the above, a double-sweep streak camera image, is the rf phase.

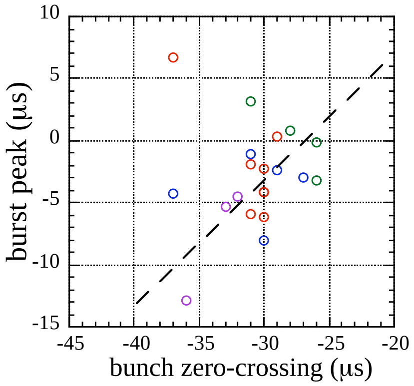

Figure 4 Bunch crossing timing and the burst peak timing to the external modulation phase.

SUMMARY

The fluctuation of the time-averaged power of CSR burst was improved by applying the rf phase modulation with 2*fs*. The periodic structure with 2*fs* was not only amplitude modulated but also phase modulated.

The improvement was not enough, however, more improvement would be possible with optimization of parameters, such as synchrotron oscillation.

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