OBSERVATION OF COHERENT SYNCHROTRON RADIATION FROM THREE TYPES OF BEAM AT NEWSUBARU

Y. Shoji[#], S. Hashimoto, A. Ando, NewSUBARU/SPring-8, LASTI, University of Hyogo
T. Takahashi, Research Reactor Institute, Kyoto University
H. Kimura, T. Hirono, K. Tamasaku and M. Yabashi, SPring-8, JASRI

Abstract

Coherent synchrotron radiation from three types of the beam was observed at NewSUBARU storage ring. One was the radiation burst from the high current beam, higher than 1.0 nC/bunch. The second was the steady state radiation from a low current but very short bunched beam. The third was the radiation pulse from the linac beam in the storage ring at just after the injection.

INTRODUCTION

Coherent synchrotron radiation (CSR) in Tera-hertz (THz) region has been a subject of great interest since it is extremely powerful and expected to have a wide application field [1]. The key of CSR in a storage ring is a bunch compression by means of low α (momentum compaction factor) operation. NewSUBARU [2] is a 1.5 GeV synchrotron radiation ring suitable for the R&D of low α operation. Six bending cells in the ring are modified DBA with an 8° invert bend between two 34° normal bends for each. This facilitates the control of the linear α (α_1) while keeping the cell achromatic and with only a small change of the natural emittance. The beam is injected from the SPring-8 linac [3] with 1.0 GeV of electron energy. At NewSUBARU, CSR from three types of the beam was observed at 1.0 GeV operation.

The one was the CSR burst from a high current beam normally obtained in low α and single bunch operation, however the low α is not an necessary condition. This CSR has been observed at many storage rings [4-13]. A fine time structure in a bunch due to the beam instabilities is the source of the CSR emission. A semi-periodic, roughly in the range of the twice of the synchrotron oscillation frequency, strong radiation burst is obtained.

The second was the steady state CSR emitted from an extremely short bunch, 10 ps FWHM or less. The ring was operated in quasi-isochronous (extremely low α) condition with very low current. This type of CSR is a quasi-dc radiation, which has no time structure except the one of RF bucket filling. Unlikely to the CSR burst, its power spectrum is continuous. This type of CSR has been observed only at some facilities [11-14].

The third was the radiation from a linac bunch observed in a storage ring. The bunch becomes longer in the storage ring and the CSR is emitted at just after the injection. A possible application of this operation is a time resolving measurement, such as a pump-probe experiment. Its pulse length is longer but has higher intensity than those of the laser-slicing method [15]. For this operation, CSR is used as a diagnostics of the bunch.

EXPERIMENTAL SETUP

Storage Ring

We control α_1 by changing two quadrupole families at the dispersive sections. A small dispersion change at the invert bends changes α_1. The α_2, the higher order momentum compaction factor, was set to almost zero by adjusting the strength of one sextupole family. The beam lifetime at the quasi-isochronous operation was about 10 hours, at α_1=1.3E-6, V_{RF}=360kV and the stored current of 4μA/bunch. More information on this subject is given in the other article [16].

CSR measurement

Because NewSUBARU has no FIR beam line at the present, we set a Si bolometer at a SR light extraction port for beam diagnostics (BL12). A low-pass filter of 35cm^{-1} was set inside of the bolometer. The radiation was modulated by the 10Hz optical chopper and the signal of the bolometer is amplified by the lock-in amplifier.

The power spectrum was measured using the Martin-Puplett type interferometer built on the optical bench. More information on this subject is given in the other article [13].

Bunch Length Measurement

For the bunch length measurements we used a streak camera setup at BL6 (beam line for bending magnet radiation). The camera's static resolution, determined by the width of the slit, was σ=0.3 ps. We operated the camera in synchro-scan mode. Details of the system were reported in SRI'03 [17].

MEASUREMENT OF CSR BURST AND STEADY STATE CSR

Radiation power

We have measured beam charge dependence of radiation power in three machine conditions.

(A; normal "incoherent" radiation) Multi-bunch, normal α_1 (α_1=1.3E-3) and normal RF voltage (V_{RF}=120kV).

(B; CSR burst) Single-bunch, normal α_1 and normal V_{RF}.

(C; steady state CSR) Multi-bunch, low α_1 (α_1=1E-5) and high V_{RF} (V_{RF}=360kV).

Fig. 1 shows the radiation power in the above three conditions. In condition (A) the radiation power was low and was almost proportional to the stored beam current. In condition (B) the radiation power had a threshold at 2.5 mA/bunch (1.0nC/bunch). Below the threshold the radiation power was the same as that of condition (A). However above the threshold the radiation power rapidly increased with the beam current. Above 4 mA/bunch the radiation power was roughly proportional to the square of the beam current. These threshold currents were lower for higher V_{RF}. In condition (C) the radiation power was high even from a very low current beam. The power was proportional to the square of the beam current, which we had expected for the steady state CSR. The CSR measurement took place at $\alpha_1 \approx 1\times10^{-5}$ and V_{RF} =360kV, where the expected bunch length was about 4ps FWHM.

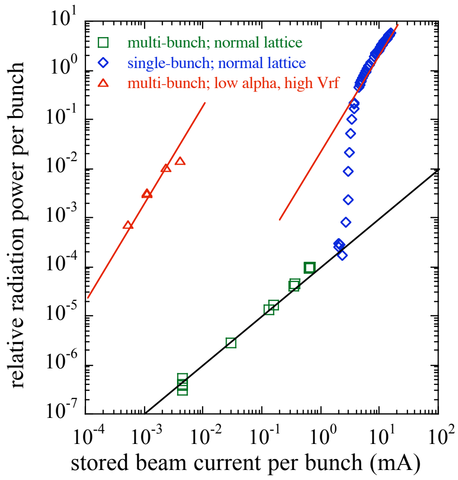


Figure 1; CSR power vs. stored beam current per bunch. Square: case (A); normal α with multi-bunch, diamond: case (B); normal α with single bunch, triangle: case (C); low α with multi-bunch.

Bunch Length

The dependence of the bunch shape on the beam current in condition (B) is shown in Fig. 2. The CSR burst started at the peak current of about 10A. We think that the main reason of the bunch deformation was the potential well distortion. Unfortunately we could not see any discontinuity in the current dependent deformation at the threshold current.

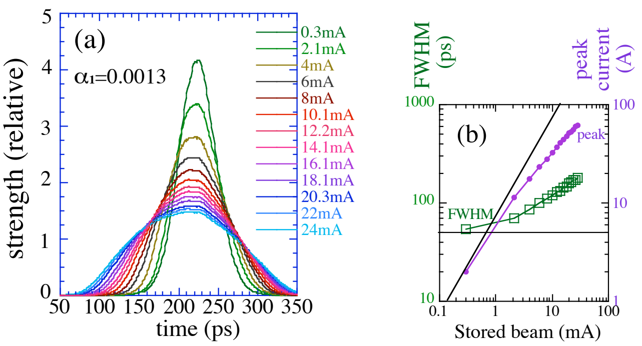


Figure 2; Beam current dependence of the longitudinal bunch shape. (a) shows the bunch shape normalized with the current and (b) shows the current dependence of the peak current and FWHM of the bunch.

In condition (C), Fig. 3 shows the measured bunch length against α_1. At that low current, less than 1.8μA/bunch, there was no current dependence of the bunch length. The well-known $\sqrt{\alpha}$ scaling law on the bunch shortening was broken at α_1< 2E-6. We think that this was because of the coherent energy oscillation [15]. Fig. 4 shows the radiation power dependence on α_1. The steady state CSR came into the observation with shorter bunch length than σ =4 ps (10 ps FWHM), which corresponds to the cut off wave-number of the beam line, about 3 cm^{-1}.

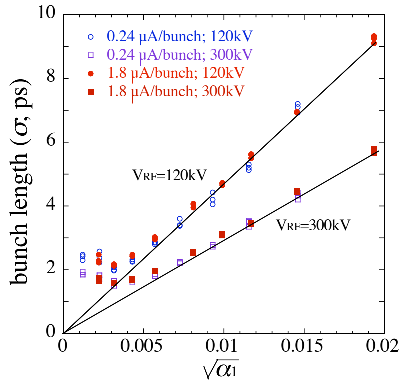


Figure 3; Momentum compaction factor α vs. RMS bunch length measured by a streak camera.

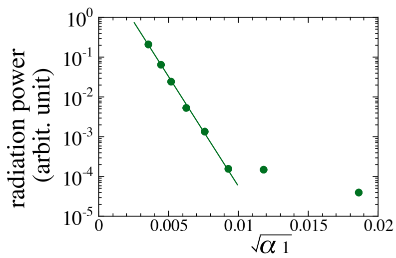
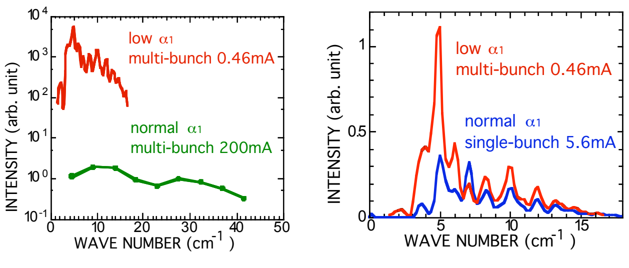


Figure 4; CSR power dependence on the momentum compaction factor (α_1). Here V_{RF}=120kV.

Power Spectrum

The power spectra in three conditions are shown in Fig. 5. The fine structure of the data was the effect of interference by the reflection at the quartz window.



(a) (b)

Figure 5; Radiation power spectrum from the stored beam. (a) shows those in condition (A): normal incoherent radiation and in condition (C): steady state CSR. (b) shows those in condition (B): CSR burst, and that in condition (C)

In condition (A) the power spectrum was broad, as was expected for the incoherent radiation. In condition (C) it had a huge power in small wave-number region. In condition (B) the power spectrum had a higher tail on the larger wave-number side than that of condition (C), although the bunch length was much longer. This meant that in condition (B) the CSR was produced by the inner structure of the bunch.

In condition (C), the shorter the bunch is, the shorter the wavelength is. Fig. 6 shows the change of the power spectrum when the bunch was compressed by raising V_{RF}.

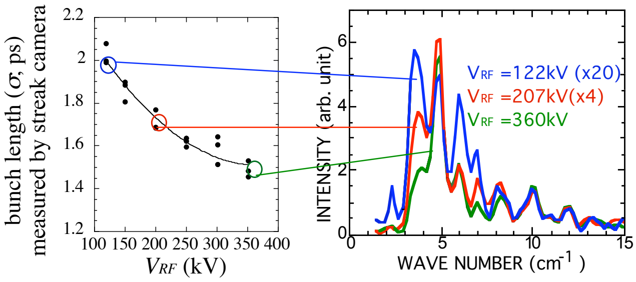


Figure 6; The dependence on the power spectrum on the bunch length. (a) shows the bunch compression by V_{RF}. (b) shows the power spectrum at three settings of V_{RF}.

OBSERVATION OF LINAC BEAM CSR

Fig. 7 shows the power in condition (A) during the accumulation and the storage. We observed a rise of the power at instances of the injection. This was CSR emitted by the beam just injected. Fig. 8 shows the bunch length of the injected beam at just after the injection measured by the streak camera [18]. The CSR could not have took place for longer than 0.1 ms. This meant the existence of a high power pulsed radiation. The rise in Fig. 7 was small because the bolometer had a poor time resolution. The injected beam had three micro bunches in one macro pulse. One micro bunch had a charge corresponded to 0.1mA, two orders higher than the bunch of condition (C).

At that instance the estimated bunch length of the micro bunch was less than 20ps base width. We have started the R&D to compress the linac pulse using ECS and inject it into the quasi-isochronous multi-pass ring. We think it would supply an extremely strong short-pulsed X-ray and extremely powerful pulsed CSR with continuous power spectrum for at least tens of turns.

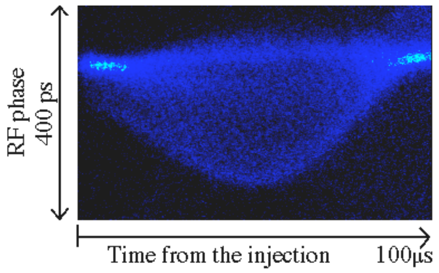


Figure 8; Change of the length of the injected bunch in the storage ring. The left end is the injection timing [18].

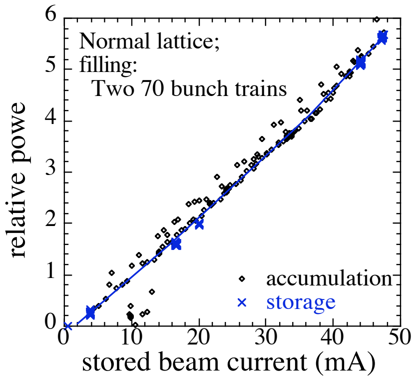


Figure 7; THz radiation power in normal condition, during the accumulation and the storage (no injection). Square data points above the line, on which the data points of the storage (cross) are, show the power rise by CSR from the linac beam.

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