OBSERVATION OF COHERENT SYNCHROTRON RADIATION AT NEWSUBARU

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Abstract

Coherent synchrotron radiation from a short electron bunch in a storage ring was observed at NewSUBARU. The ring was operated with energy of 1 GeV and qusi-isochronous mode. The linear momentum compaction factor was smaller than $2x10^{-5}$ and the bunch length was shorter than 5 ps (FWHM). An extremely powerful radiation was observed from a low current beam, and power spectrum was measured by an interferometer.

INTRODUCTION

Terahertz (THz) electromagnetic wave has been a subject of great interest and coherent synchrotron radiation (CSR) in THz region has been observed at several storage rings. CSR is emitted in burst mode [1-5] or in low α mode [6,7]. In the burst mode longitudinal structure of a bunch due to beam instability is the source of CSR emission. In the low α mode or qusi-isochronous mode, the special ring optics is chosen; where momentum compaction factor α becomes very small and bunch length is shorten to the same order as wavelength of CSR.

The NewSUBARU electron storage ring [8] has the unique feature, i.e., it has six inverse bending magnets in addition to twelve normal bending magnets in order to achieve variable α easily. The ring has been operating with positive α=+0.0013 in usual user time and has been successfully operating with qusi-isochronous mode [9] and negative α mode [10] in machine studies.

The lattice functions of the qusi-isochronous mode calculated by MAD [11] is shown in Fig. 1.

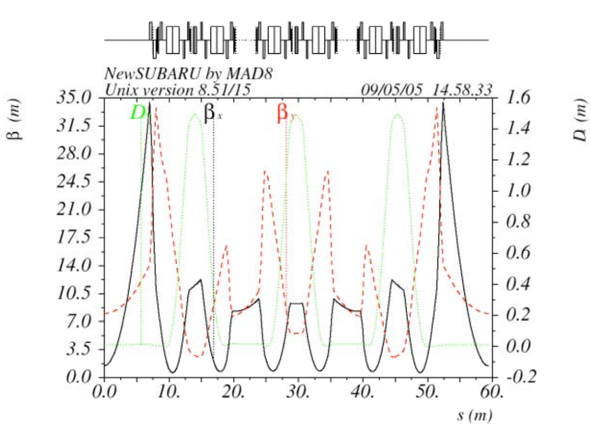

Figure 1; Lattice functions (the half of the ring) in the qusi-isochronoous (low α) mode calculated by MAD.

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The bunch length was measured by a streak camera (Hamamatsu C6860) [9]. In Fig. 2 the measured bunch length is plotted against α, which is estimated from measured synchrotron oscillation frequency. The minimum bunch length is 1.7 ps in standard deviation with the RF voltage of 300 kV, which is higher than 120 kV in the normal α operation.

In this paper we present the first results of CSR measurements in burst and in qsui-isochronous operation of the NewSUBARU storage ring. The power and spectrum of CSR from a short bunch in the low α mode are compared to those in the normal α mode.

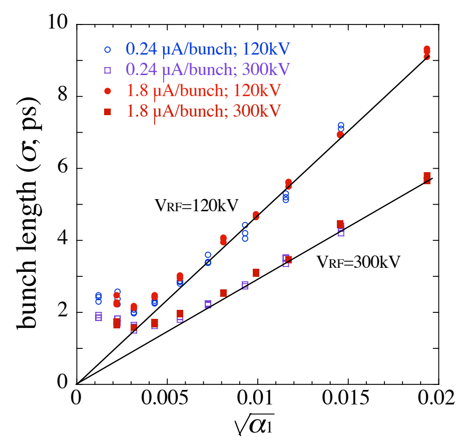

Figure 2; Momentum compaction factor α vs. RMS bunch length measured by a streak camera.

EXPERIMENTAL SETUP

There is no special beamline for use of far-infrared in the NewSUBARU. Therefore the CSR measurements were temporally carried out at BL12, where electron beam profile is measured by the direct observation of visible synchrotron radiation and by the interferometer with double slit [12].

Synchrotron radiation from a normal bending magnet is taken out of the inside vacuum chamber into the atmosphere by the Au-coated Cu-block mirror through a quartz window. Its acceptance of 8x8 $mrad^2$ is determined by slit size of an absorber. An optical chopper (SRS SR540) modulates continuous light to pulse, and its chopping frequency is 11 Hz.

The power of THz electromagnetic wave is measured with a Si bolometer custom-designed by Infrared Lab. A longwave pass filter with cut-off wavenumber of 35 cm^{-1} is built in the bolometer cooled with liquid He. The output signal of the bolometer is amplified by the lock-in amplifier (EG&G 7220).

In case of CSR power measurement, the chopped light is directly feed from the M1 mirror to the bolometer. The distance between the radiation emission point and the bolometer is about 2.3 m.

In case of spectrum measurement two spherical mirrors (f=100, 250) are used to collect the light and focus it on the Martin-Puplett type interferometer built on the optical bench. The experimental setup for CSR power spectrum measurement is shown in Fig.3.

Measurement devices are located in the shielded tunnel and can be remote-controlled. Data acquisition and analysis are performed by a system based on PC and LabVIEW software.

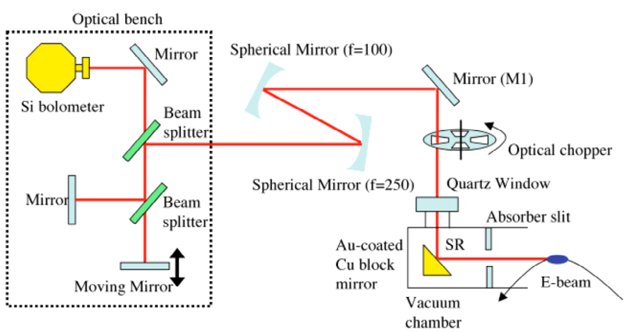

Figure 3; Setup of CSR spectrum measurement. In case of power measurement, CSR is directly feed from M1 mirror to Si bolometer.

MEASUREMENT OF COHERENT SYNCHROTRON RADIATION

CSR power and spectrum measurement were performed in the normal and the low α modes. The ring was operated with single-bunch or multi-bunch. In multi-bunch operation the number of bunch was 140. The harmonic number of the ring is 198. The typical parameters are shown in Table 1.

Table 1: Typical parameters of normal and low α modes

	Normal α	Low α
α	+1.3E-3	+1.0E-5
RF voltage	130 kV	360 kV
Bunch length (rms)	9.80 mm	~ 0.73 mm
Bunch current, I_b	1.4 mA	3.3 μA
CSR power per I_b (a.u.)	1	2E+6

The result of CSR power measurement is shown in Fig 4. The radiation power divided by the number of bunch is plotted as a function of bunch current. In the normal α operation radiation power increases almost linearly up to 2 mA, above which it shows a rapid rise and a quadratic dependence on bunch current. This experimental result shows that even though bunch length is relatively long in the normal α mode bursts of CSR are generated above the 2 mA threshold. On the other hand, in the low α mode radiation power per bunch shows a quadratic dependence on bunch current in low current regime. Although the bunch current is low and under the threshold of beam instability, CSR generated from a short electron bunch is extremely powerful.

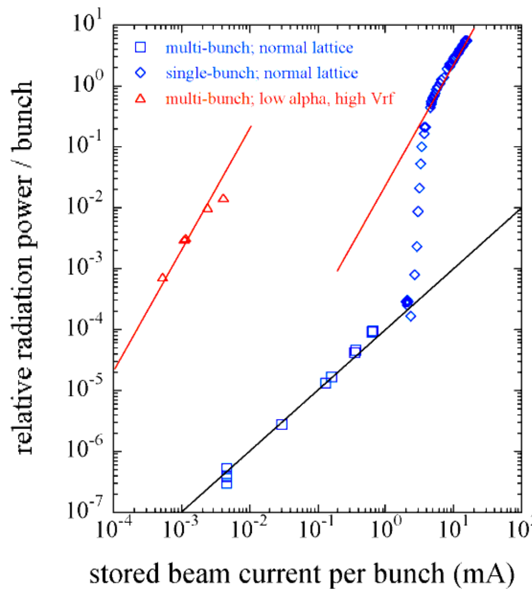

Figure 4; CSR power vs. stored current per bunch. (squre: normal α with multi-bunch, diamond: normal α with single bunch, triangle: low α with multi-bunch)

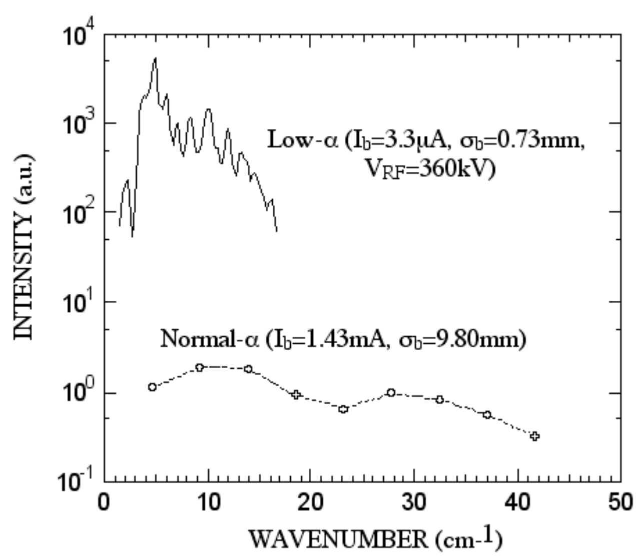

Figure 5; CSR power spectrum in the normal and the low α modes.

The result of spectrum measurement is shown in Fig. 5. Since bunch current in the normal α mode is 1.43 mA, which is under the threshold for emission of CSR bursts, this can be considered as incoherent radiation. This

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incoherent radiation power is almost constant in measured waveneumber range. Although bunch current in the low α mode is 433 times lower than that in the normal α mode, the radiated CSR is up to $5x10^3$ more powerful. Thus the CSR power is about $2x10^6$ more powerful than incoherent synchrotron radiation at the same bunch current. The number of electrons in a bunch N_e is about $8.2x10^6$ at I_b=3.3μA. The peak of the spectrum is found around at $5cm^{-1}$ in wavenumber, that is, 2 mm in wavelength. This corresponds to 2.7 times bunch length. The fine structure found in the low α mode may be caused by interference between both surfaces of the parallel-plate quartz window. The attenuation where wavenumber is less than three is due to cut-off effect by a vacuum duct.

FUTURE PLAN

We have successfully observed CSR at NewSUBARU with temporal use of the BL12 for visible light. However it was inconvenient to change experimental setup because all measurements were performed in the shielded tunnel. For further CSR measurement at BL12, THz radiation will be extracted to experimental hall using several mirrors. To avoid interference in spectrum measurement, the planar-plate quartz window will also be replaced by the wedged one.

We are now planning to make a new extraction port in the vacuum chamber at an inverse bending magnet, where larger aperture with 70 mrad in horizontal and 100 mrad in vertical can be expected to generate more powerful CSR. The calculated power spectrum of CSR from this port is shown in Fig. 6, assuming 6.25 μA/bunch and 160 bunch-filling.

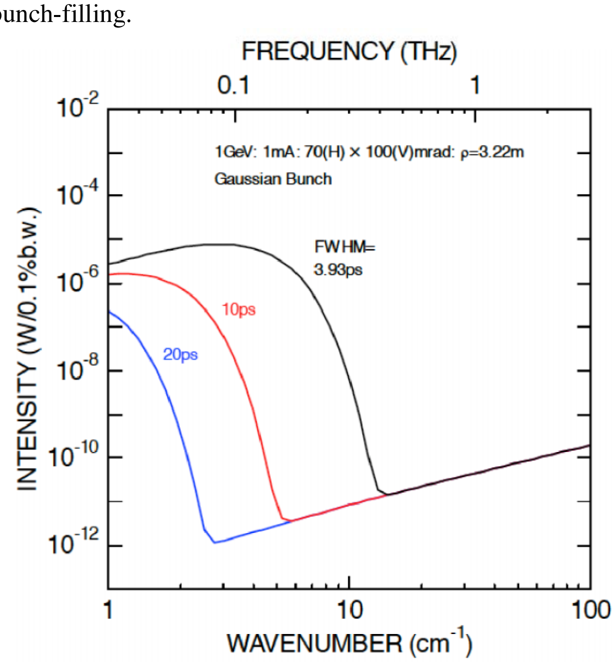

Figure 6; Calculated CSR power spectrum from the planning extraction port with larger aperture.

SUMMARY

CSR was measured at the NewSUBARU storage ring in burst and in the low α modes. An electron beam with relatively long bunch length radiates CSR in bursts above bunch current of 2 mA. In the low α mode where the momentum compaction factor α is smaller than $2x10^{-5}$ and the bunch length is shorter than 5 ps (FWHM), an intensive CSR is measured from a low current beam. The power of CSR per bunch current is up to $2x10^6$ larger than the power of incoherent synchrotron radiation at the same bunch current. This numerical value is the same order as the number of electrons in a bunch N_e.

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