COHERENT SYNCHROTRON RADIATION PRODUCTION AT THE CANADIAN LIGHT SOURCE

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Abstract

Coherent Synchrotron Radiation (CSR) is produced when short bunch lengths are set up in the Canadian Light Source storage ring. To achieve short bunches, large negative dispersion is introduced into the straight regions of the lattice such that the momentum compaction can be made to approach zero. In this way CSR has been observed using a few (1-3) bunches with currents up to 10 mA per bunch at the nominal operating energy of 2.9 GeV. Attempts to produce CSR with low bunch current in many bunches were unsuccessful at 2.9 GeV. At 1.5 GeV, however, it is possible to achieve CSR with a total of 5 mA stored in 70 bunches. CSR production is enhanced by operating at a horizontal tune where the chromaticity can be kept near zero. Tracking simulations in longitudinal phase space indicate enhanced stability at tunes lower than the nominal tune. The optimum tune does not depend solely on the fractional tune but rather the whole tune. There is a tune "window" at the centre of which longitudinal stability can be maximized.

BEAM OPTICS STUDIES

Making Short Bunches

CLS [1] has a twelvefold symmetric lattice. The machine is normally tuned with a horizontal dispersion, η_x, in the straight sections, of 0.15 m. Short bunches are produced by making a negative dispersion in the straights which brings the momentum compaction, α_c, close to zero. Using three families of quadrupoles the horizontal and vertical tunes and the dispersion can be controlled.

In initial attempts to produce CSR from short bunches the tunes (ν) were kept at the nominal operating tunes of 10.32 and 4.32. At these tunes, $\alpha_c = 6.7 \times 10^{-5}$ is achieved with a dispersion of -0.530 in the straights. Parameters for normal and the initial CSR setups are shown in Table 1. Chromaticities (χ) are those used to optimize beam stability. The table includes values for the nominal machine energy of 2.9 GeV and for 1.5 GeV. Bunch lengths (1σ) are from tracking at the damped energy spread (δ=dE/E). At the lower machine energy the bunch length is reduced almost by a factor of two. The machine functions for the CSR setup are shown in figure 1.

Table 1. Parameters for Normal and Initial CSR Setups.

	Normal	CSR	
α_c	0.0038	0.000067	
ν_x / ν_y	10.22 / 4.32	10.22 / 4.32	
χ_x / χ_y	2 / 4	6 / 4	
	2.9 GeV	2.9 GeV	1.5 GeV
δ (%)	0.11	0.093	0.048
bunch (ps)	31	3.3	1.9

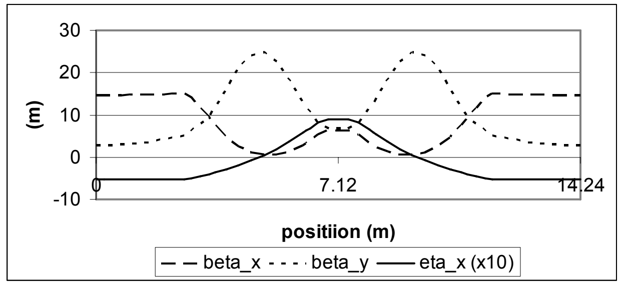
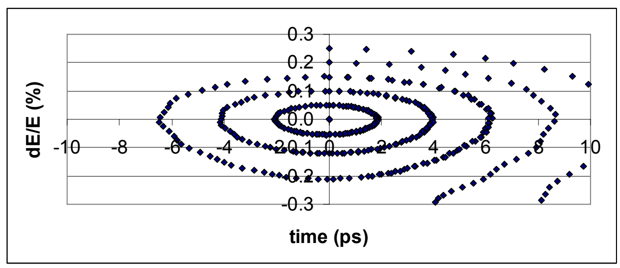


Figure 1. Machine functions (1 cell) for the initial CSR setup.

Longitudinal Stability

To check the effectiveness of the small momentum compaction tracking in longitudinal phase space was performed. Results for the CSR setup of Table 1 are shown figure 2

At the nominal tunes it is necessary to set the horizontal chromaticity to a rather large value in order to achieve good longitudinal stability and a large dynamic aperture. This was confirmed with particle tracking [2].



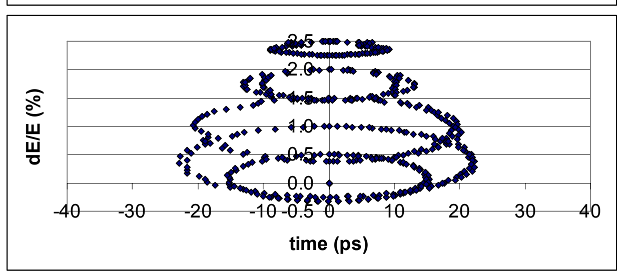


Figure 2. Longitudinal phase space tracking at different electron energies (dE/E) for $\alpha_c = 6.7 \times 10^{-5}$ at the nominal tunes. Top: χ_x/χ_y = 2/2. Motion is stable up to dE/E ≈ +0.15%. Bottom: χ_x/χ_y = 6/4. Motion is stable up to dE/E ≈ 2.5%. (Note: orbits appear to cross because this is a 2D slice of a 4D phase space.) In both cases the bunch lengths (from tracking) are effectively the same.

A Better Tune

Various horizontal tunes were investigated to see if the longitudinal stability could be improved at a lower horizontal chromaticity. At a horizontal tune of 10.05, $\alpha_c = 6.8 \times 10^{-5}$ is achieved with η_x = -0.483. Good longitudinal stability is achieved with χ_x/χ_y = 4/2. Compared to the nominal tune the stability is seen to improve at χ_x/χ_y = 2/2. The tracking results for this setup are shown in figure 3. No significant change in the bunch length results from changing the tune even though the temporal spread over all energies is much broader.

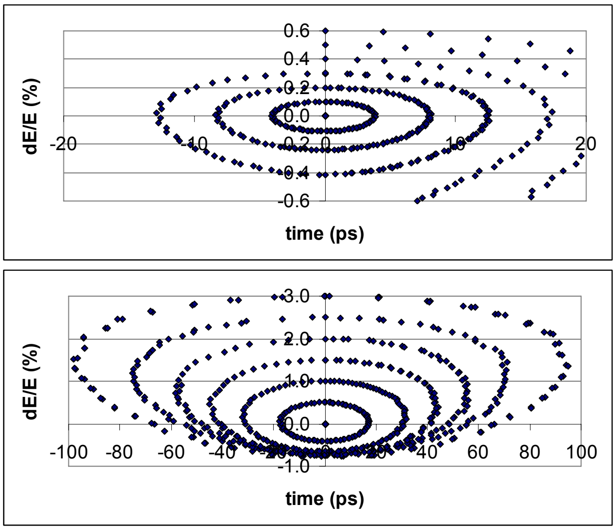


Figure 3. Longitudinal motion at a horizontal tune of 10.05. with α_c = 6.8x10^{-5}. Top: χ_x/χ_y = 2/2. Motion is stable up to dE/E ≈ 0.3% (compare to figure 2). Bottom: χ_x/χ_y = 4/2. Motion is stable up to dE/E ≈ 3.0%.

The tune of 10.05 was of interest since it was, in practice, more easily achievable with the real machine (see experimental results). A potentially better setup results when the tune is set to 9.78. At this lower tune, α_c = 7.0x10^{-5}, 0.85x10^{-5} and 0.32x10^{-5} were investigated with χ_x/χ_y = 2/2. η_x = -0.483 is required to achieve the higher α_c. The results are shown in figure 4.

The best tune for longitudinal stability with small horizontal chromaticity is at a lower tune of $\nu_x \approx 9.78$. For this tune, it is possible to achieve stability at very small momentum compactions. At α_c = 0.83x10^{-5} the bunch length at 1.5 GeV (dE/E ≈ 0.05%) is about 0.5 ps and at α_c = 0.32x10^{-5} a bunch length of 0.25 ps is stable.

The longitudinal stability does not depend solely on the fractional tune. Keeping χ_x/χ_y = 2/2 the stability was checked at tunes of 9.22 and 10.78. Results are summarized in Table 2. Comparing the stability for $\alpha_c \approx$ 7.0x10^{-5} there is maximum stability near 9.78. At this tune the energy stability is about 8 times that of the nominal tune of 10.22. Furthermore, the transverse dynamic aperture is increased from 22 mm at the nominal tune to 38 at 9.78. The lower tune with the lower horizontal chromaticity is optimum for CSR production.

EXPERIMENTAL RESULTS

Experimental Procedure and Diagnostics

To achieve small momentum compaction, the beam was first injected into the storage ring at the normal operating tunes, chromaticities and dispersion. Next the tunes and chromaticities were adjusted to the desired final value. Finally the dispersion was decreased in small steps while keeping the tunes and chromaticities constant. Orbit correction was applied during most of the process until the response functions were no longer applicable.

At each step the beam size was observed with a streak camera in the optical synchrotron radiation (OSR) diagnostic beamline [3]. As well, the synchrotron tunes were monitored to confirm the decreasing momentum compaction. THz radiation was measured with a silicon bolometer on the CLS far infrared beamline [4].

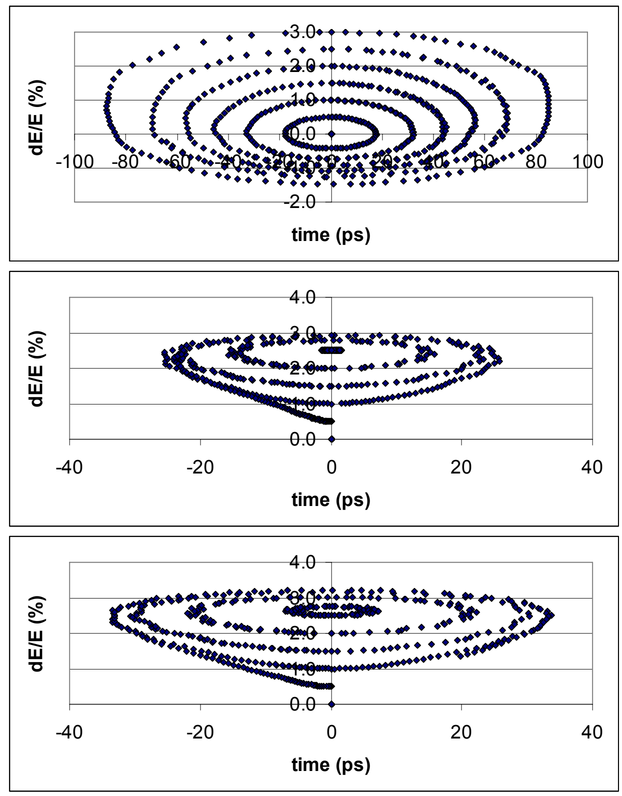


Figure 4. Longitudinal motion at horizontal tune of 9.78 and χ_x/χ_y = 2/2. Above: α_c = 7.0x10^{-5}. Motion is stable up to up to dE/E ≈ 1.3%. Middle: α_c = 0.83x10^{-5}. Motion is stable up to dE/E ≈ 0.2%. Bottom: α_c = 0.32x10^{-5}. Motion is stable up to dE/E ≈ 0.05%.

Table 2. Beam Stability at Various Tunes with χ_x/χ_y = 2/2. Length is for energy spread of ±0.5%.

ν_x	η_x	α_c (x10^{-5})	dE/E (%) stability	length (ps)
10.78	-0.783	6.7	unstable	-
10.22	-0.530	6.7	0.15	2.0
"	-0.538	1.0	unstable	-
10.05	-0.483	6.8	0.30	2.0
"	-0.491	0.85	unstable	-
9.78	**-0.424**	**7.0**	**1.20**	**1.9**
"	-0.4314	0.83	1.00	0.5
"	-0.432	0.32	1.00	0.25
9.22	-0.342	6.7	0.20	1.3

Early Results

In January, 2007, THz radiation was first observed [5] at 2.9 GeV and with the tune at 10.22. A single 10 mA bunch was used. Enhanced radiation was first observed at a dispersion of -0.45 m and continued to increase as the dispersion approached -0.52 m. The bunch length (1σ) at η_x=-0.50 measured with a streak camera was about 13 ps. This was much larger than expected and was probably due to potential well distortion by the large bunch current density [6]. At a wave number of 10 cm^{-1} the photon intensity was up to 10,000 times that of non-coherent radiation as shown in figure 5.

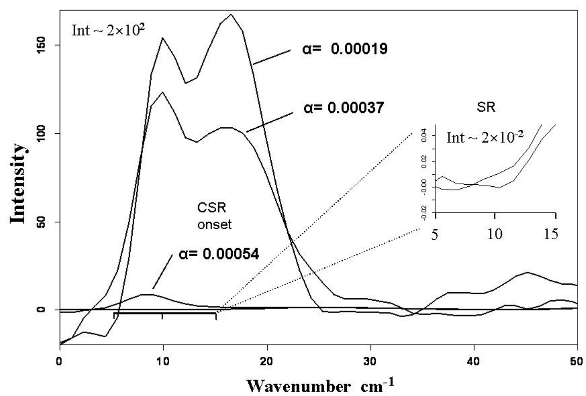


Figure 5. THz radiation intensity at various momentum compactions (α in this figure). Inset figure shows non-CSR intensity.

At 2.9 GeV and with the tune at 10.22 attempts to produce CSR with long bunch trains with low bunch current were unsuccessful.

Results at 1.5 GeV

To attempt to produce CSR with longer pulse trains with low bunch current, the storage ring was set up for 1.5 GeV operation. At the same time the tune was lowered. Since the tune is adjusted after current is injected it is difficult to go to tunes less than 10.0 as this requires crossing an integer resonance. Horizontal and vertical tunes of 10.08 and 4.27 were achieved.

With a current of 5 mA in 70 bunches CSR was observed at α_c = 0.00068 (η_x = -0.41). (Machine parameters are based on modelling.) As with earlier CSR production, the intensity was up to 10,000 times that of non-CSR radiation. A plot that selects peaks of intensity is shown in figure 6. These peaks possibly arise from the vacuum chamber geometry and may limit the usefulness of CSR radiation for doing experiments requiring high resolution (see [5]). A possible improvement to the chamber design is being investigated.

Some variations in chromaticity were investigated but it appears that CSR production, at this time, is insensitive to this second order effect. Consequently, as used with the longitudinal simulations, both planes were set to χ = +2.

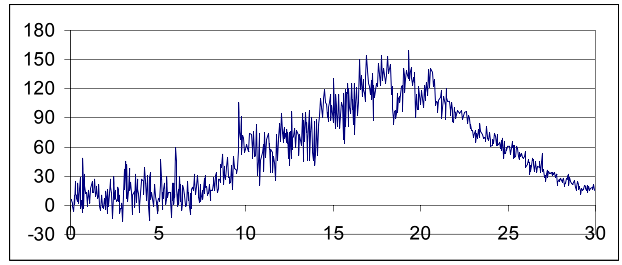


Figure 6. THz radiation intensity for the 1.5 GeV setup. Axes are as in figure 5.

Improved production and lifetime are expected at a tune of 9.78 and will be investigated in the near future. This tune has been chosen since it is the anti-tune of the normal setup and it may facilitate injection directly at the desired lower tune.

CONCLUSIONS

To increase the longitudinal stability of the beam tune for CSR production, the tune should be adjusted to maximize the energy acceptance. The relative acceptance can be further increase by operation at a lower electron energy. Under these conditions improved CSR production has been observed at the CLS.

ACKNOWLEDGEMENTS

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[6] for example, see: J. Corbett, W. Cheng and X. Huang, "Short Bunch Operation at SPEAR3", these proceedings.