LOW ALPHA CONFIGURATION FOR GENERATING SHORT BUNCHES

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Abstract

Generating short bunches for time resolved studies or the generation of Coherent Synchrotron Radiation (CSR) has been done at many other light sources and is of increasing interest in the user community. Some light sources not designed with ps bunches can usually tune the lattice to reduce the bunch length without much difficulty, sometimes referred to as a Low Alpha mode. At the Australian light source a low alpha configuration has been investigated. The results looking into the "shaping" of the momentum compaction factor, beam stability and current limitations will be presented.

INTRODUCTION

A number of light sources, ANKA [1], BESSY [2], ELETTRA [3] and SPEAR3 [4], have reported CSR generation in the storage ring. As part of future developments at the AS we have started some investigations into the feasibility and stability of running the storage ring in a low-α configuration for the Far Infra-Red user community and beamlines that would like to do finely tuned time resolved experiments. This note will report on some of the initial results of our studies into a low-α configuration at the Australian Synchrotron (AS).

The AS storage ring is a 3 GeV Chassman-Green type lattice with three families of quadrupoles to control the two tunes and the dispersion. In such a lattice is is possible to control the momentum compaction factor, α_c, by adjusting the dispersion in the straights (to negative values) to reduce the integral, $\int \eta(s)/\rho(s)ds$, where η is the horizontal dispersion and ρ the bending radius. Table 1 below shows some of the relevant parameters for the different configurations.

Table 1: Lattice parameters for different configurations. The dispersion in the straight sections, η, controls α_1. Further reductions are achieved by reducing the dispersion.

Parameter	$\eta = 0.1$ m	$\eta = -0.75$ m
α_c	2.11×10^{-3}	0.50×10^{-3}
f_s (kHz)	14.9	7.2
σ (ps/mm)	23 / 6.9	10 / 3.1

The machine was calibrated using LOCO [6] in Matlab. Further reduction of α_1 through the manipulation of the dispersion is achieved by using a model calculated inverted Jacobian with three families of quadrupoles and three parameters (two tunes and dispersion).

CSR is emitted when the length scale of the longitudinal bunch density is comparable to the critical length, $\sigma_c = \lambda_c/2\pi = \sqrt{4b^3/\rho}/2\pi = 0.66$ mm, where $\rho = 7.7$ m is the bending radius and $b = 32$ mm the full vertical aperture of the AS storage ring vacuum chamber. CSR can be detected for bunch lengths up to $\sigma_s = \sigma_c\sqrt{ln(N))} = 3.1$ mm [3]. Thus for dispersions less than -0.75 m CSR should be detectable. This however is only a rough guide and as observed at other light sources significant bursts of CSR can occur in longer bunches due to local density modulations. At the AS a sawtooth like pattern of emission was observed beginning around $\sigma = 4$ mm with 14 mA in a single bunch. The following sections will show some results from the Far-IR beamline, bunch length measurements as well as addressing some optimisation issues such as the manipulation of α_2 and orbit stability.

OBSERVATION OF CSR

Measurements were taken on the Far-IR & High Resolution beamline using a Bruker IFS125HR with a Si-B helium cooled bolometer. The measurements in Figure 1 show that the emission appears only between 10 and 20 wavenumbers at 9 mA in single bunch mode and is an increase in intensity of 5×10^4 at its peak. This was only with a modest decrease in α_1 to 5.8×10^{-4} (a factor of only 3.8). When we look at the raw data from the interfer-

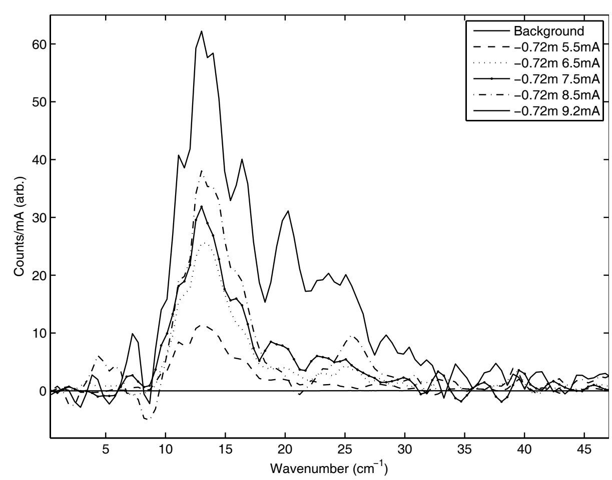

Figure 1: IR spectra showing emission between 10 and 20 wavenumbers with a lattice at a dispersion of -0.72 m instead of -0.75 m because of difficulties with injection at that time.

ometer a sawtooth pattern is observed and appears to grow with increasing current density. This is most likely the same phenomena observed at other light sources called the sawtooth instability and is associated with the quadrupole bunch phase oscillation mode [7]. The onset appears to be

>5.5 mA (see right pane of Figure 2) and correlates with the point at which the bunch length deviates from the potential well model in the top line in Figure 4.

To verify the time structure, the interferometer mirror was put in a static position and essentially used the bolometer as an IR intensity detector. The raw output from the Bolometer was put into a scope and the sawtooth pattern was observed to have a period of just over 2 ms as shown in the left pane in Figure 2. This is close to the damping time of the storage ring. It is believed that this instability causes longitudinal perturbations that give rise to burst of CSR (burst mode). Attempts to detect the quadrupole mode with the spectrum analyser, $2f_s$, were not successful, probably due to the current setup. As observed at other light

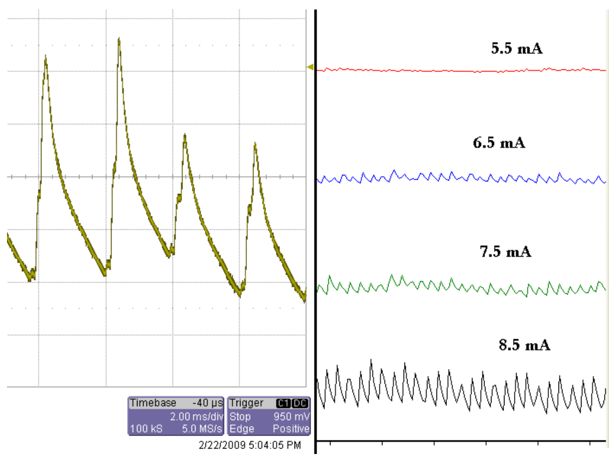

Figure 2: (Right) Data from the interferometer showing the sawtooth instability growing as the current is increased. (Left) IR mirror in a static position and we observed intensity fluctuations with a period of ≈ 2 ms in a sawtooth pattern.

sources the burst-mode CSR emission causes large intensity fluctuation that are not readily controllable/repeatable and is thus not useful for the beamline.

BUNCH LENGTH MEASUREMENTS

An Optronis streak camera was used to measure the longitudinal fluctuations and to confirm the sawtooth instability observed on the IR interferometer. The streak tube has dual sweeping plates allowing for a fast sweep to measure the ps bunch length and a slow sweep to monitor the bunch length over ms time scales. The primary sweep unit is a 250 MHz synchroscan unit that can sweep at 50, 25 and 15 ps per mm, so each sweep can separate adjacent bunches in the 500 MHz bunch train in the storage ring. The secondary sweep unit can sweep at 5 ms per mm in the perpendicular direction to the primary sweep unit, resulting in a time-time plot of the bunch length with time. The secondary sweep is triggered at 1 Hz and the full scale is 35.7 ms. The sawtooth instability was observed with streak camera, showing a semi-periodic 2ms bunch length fluctuations as shown in Figure 3.

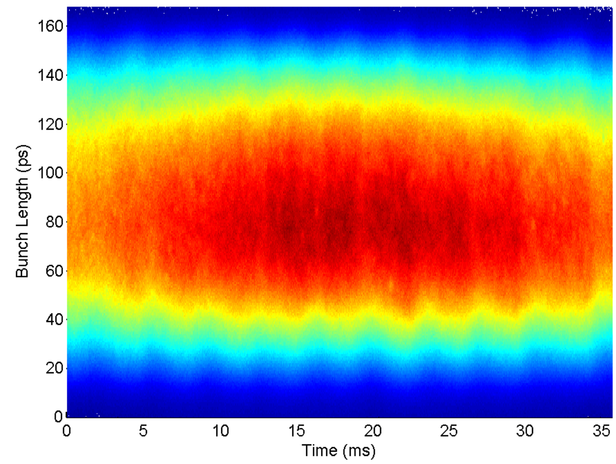

Figure 3: Streak camera measurements show bunch length oscillations with the same period as the sawtooth instability seen on the IR interferometer. $\eta = -0.75$ m with a single bunch current of 9.2 mA.

Bunch length measurements were made for different single bunch currents and for $\alpha_1 = 11.6 \times 10^{-4}, 6.4 \times 10^{-4}, 3.5 \times 10^{-4}$). The line plot in Figure 4 refer to the calculated and fitted theoretical bunch length dependence on the current, I, given by the Hassinski equation that describes the lengthening due to potential well distortions [8][9]. As expected Figure 4 show that at larger current densities the bunch starts to elongate and deviate from the potential well model as it approaches or exceeds the microwave threshold. In fitting the curves it seems that the ring inductances is much lower than expected at 25 nH (top line) and 15 nH (middle and bottom line) with the fixed resistance, R, set to 1600 Ω (based on previous measurements as it is not expected to change with smaller bunches). The expected that the ring inductance was 70 nH given previous measureemnts in [8]. More points at lower currents are required to do proper fits, so further study would be required to understand these results.

MINIMISING α_2

Significant reduction in the bunch length also requires the reduction of second order momentum compaction factor, α_2. This can be minimised by optimising the sextupoles. The AS storage ring has 4 families of sextupoles of which two are for chromatic correction and the remainder can be used to optimise α_2. Experimental measurement of α_2 is determined by measuring the change in the synchrotron tune, f_s, as a function of the change in the RF frequency, f_{rf} according to the equation ([5],[4]),

$$\nu_s = \sqrt{\frac{hV_{rf}cos\phi_s}{2\pi E/e}} \left(\alpha_1^2 - 4\alpha_2\frac{\Delta f_{rf}}{f_{rf}}\right)^{1/4} \quad (1)$$

Figure 5 would indicate that the optimal setting for SFA

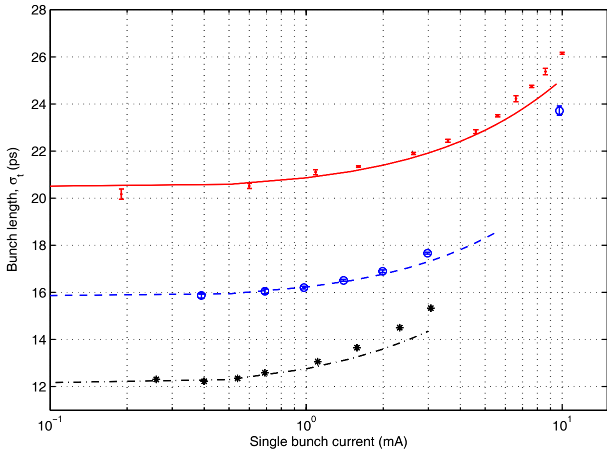

Figure 4: The line plots show the lengthening due to potential well distortions for a given fixed resistive, R, and inductive, L, value of the storage ring and different α.

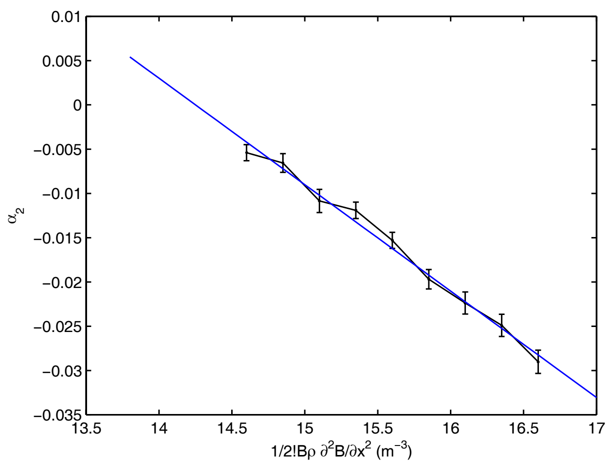

Figure 5: Measure of the change in the second order momentum compaction factor as a function of sextupole settings by measuring the change in Δf_s with $\Delta f/f_{rf}$. There are four families of sextupoles, one of which was varied, two others adjusted to keep the chromaticity constant around $\xi_x = 2$ and $\xi_y = 4$ and the last family kept constant.

that was varied is between 13.5 and 14.5 Amps. The smallest bunch length achieved so far was with $\eta = -0.92$ m with a measured $f_s = 1.3$ kHz which gives a theoretical $\alpha_1 \approx 2.11 \times 10^{-5}$ which is a 100 fold decrease from nominal. At the time we could not verify CSR emission as the beamline was not available. A problem at this configuration is that the machine's orbit stability is very sensitive to small energy fluctuations (from magnets) or phase shifts in the RF system.

ORBIT STABILITY

At very small values of α_1 and large absolute dispersions the lattice is very sensitive to changes in the beam energy. The smallest measured synchrotron frequency during a test was around 1.3 kHz with $\alpha_1 \approx 2.11 \times 10^{-5}$. The difference orbits show distinct dispersion orbits with peaks of 220 μm in the center of the arcs. With dispersions around 1.7 m this corresponds to peak to peak variations of $\Delta p/p = \delta_e = 1.3 \times 10^{-4}$. In RF terms this would only be changes of a few hertz which is certainly possible however noise in the RF system is harder to determine. A more likely source is from the dipole power supply whose DCCT readback also show a six sigma fluctuation of around 2.5×10^{-4}. The dominant noise is a clearly seen to be 50 Hz from the BPMs. The AS currently do not have a fast global orbit feedback system to correct for such orbit fluctuations, however even with such a system it would be unlikely that it could cope with such large deviations.

DISCUSSION

Some work has been done to understand the properties of the ring with smaller and smaller values of α_1. More study would be required to understand the instabilities seen here. However it is clear from work done at other light sources that we would need to achieve steady state emission from sub-mm length bunches for the CSR to be usable. This can only be achieved at low bunch current densities and very small values of α_1. To deal with the issue of noise another option would be to reduce the energy of the electron beam as there is a strong dependence of the bunch length with energy (approximately $\sigma \propto E^{3/2}$ [2]). By reducing the energy to 2 GeV it is possible to reduce σ by a factor of 2 and keep larger values of α so the ring is less sensitive to noise. This will be investigated.

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