BUNCH LENGTH MEASUREMENTS FROM THE INCOHERENT SYNCHROTRON RADIATION FLUCTUATION AT SOLEIL

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Abstract

Bunch length measurements can be made by analysing the pulse to pulse intensity fluctuation of the incoherent synchrotron radiation as it has been reported at the ALS [1]. Such a method has been tested at SOLEIL for picosecond bunch durations, at several wavelengths and bandwidths in the visible range, using an avalanche photodiode. Thanks to the low-α optics, the lengths of 15 µA bunches as short as a few ps have been measured in good agreement with the streak camera results. We first used the radiation from a bending magnet, and then from a HU640 undulator that enhances the photon flux. Using the radiation from an undulator also shows that the method is still valid when the number of spikes emitted by an electron bunch is reduced to one thousand. We intend to use this result to measure the very short bunch length of the femto-slicing operation foreseen at SOLEIL.

INTRODUCTION

A very simple setup has been described in [1] with which short electron bunch lengths are measured, taking into account the radiated energy fluctuation emitted by the bunch from one turn to another. Thanks to a filter of narrow bandwidth Δw inserted into the radiation path, the measured fluctuation δ should be correlated to the bunch length σ_t with:

$$\delta^2 = \frac{1}{\sqrt{1+M_t^2}\sqrt{1+M_x^2}\sqrt{1+M_z^2}}$$

where $M_{x/z}=\sigma_{x/z}/\sigma_{xc/zc}$ are the transverse mode numbers in the horizontal and vertical planes, $\sigma_{x/z}$ the rms horizontal and vertical beam sizes at source point, $\sigma_{xc/zc}$ the transverse coherence sizes, and $M_t=\sigma_t/\sigma_{tc}$ the longitudinal mode number with σ_{tc} the rms coherence time relative to Δw [2]. The radiation in the bandwidth of interest has to be incoherent and the bandwidth Δw of the filter has to be large enough to induce a sufficiently large number of longitudinal modes, but small enough to fulfill $\sigma_w \ll c/\sigma_{x/y}.\sigma_{\theta x/y}$ where $\sigma_{\theta x/y}$ is the rms radiation divergence.

This method could be of high interest at SOLEIL to measure the ultra-short bunch lengths of 50-70 fs-fwhm expected in the femto-slicing operation [3]. Indeed, such duration would be below SOLEIL's present femtosecond streak camera resolution of 300 fs-fwhm.

EXPERIMENTAL SETUP

A first setup has been installed on the Diagnostic beamline that uses the visible light from the C01-1 bending magnet (BM) 0.5° exit. It is settled in parallel to two streak cameras whose resolutions are respectively of 2 and 0.3 ps-fwhm.

As shown in figure 1, the visible light is focussed on the 0.5 mm^2 sensitive area of an avalanche photodiode (APD). Two APD have been used, one which exhibits a high cut-off frequency to permit an easy length measurement with the 352 MHz multibunch filling pattern (S6045-02, 900 MHz), and the other which enhances the sensitivity at 532 nm wavelength (S9074, 400 MHz). The signal from the photodiode is amplified (Hamamatsu C5658 SPL, 1 GHz bandwidth, 40 dB gain) and sent to a digital oscilloscope (LeCroy Wavepro 7100, 1 GHz bandwidth, Dual 20 Gsamples/s) for data recording and analysis. The oscilloscope was triggered with the 846 kHz revolution clock of the SOLEIL Storage Ring.

Several interferometric filters in the visible range (Melles Griot) have been used to work with different wavelengths (514, 532, 632 nm) and different bandwidths (0.8, 3, 1.2 nm fwhm), the former acting on the transverse coherence and the latter on the longitudinal one.

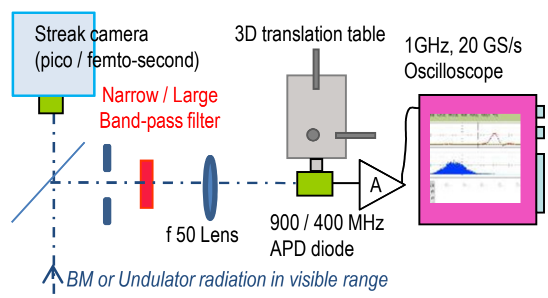

Figure 1: Bunch length measurement setup at SOLEIL.

APD NOISE MEASUREMENT AND FLUX OPTIMISATION

There is an instrumentation noise mainly due to the APD. It consists in fluctuations that can be clearly identified and have been measured using a 100 nm bandwidth filter. Such a wide bandwidth eliminates any significant fluctuations from the spike phenomenon signal. The parasitic noise depends on the incident photon number and on the amplifier gain. Since this noise has a Gaussian distribution like the fluctuations produced by the useful signal due to the spike phenomenon, it is legitimate to subtract quadratically their rms values $\delta_{M[LBW]}$ in order to retrieve the actual rms fluctuations δ that characterize the bunch length:

$$\delta_M^2 = \frac{\sigma^2 - \sigma_0^2}{\left(\langle I\rangle - \langle I_0\rangle/2\right)^2}\ ;\ \delta^2 = \delta^2_{M[Narrow\ BW]} - \delta^2_{M[LBW]}$$

where σ and $\langle I\rangle$ are the standard deviation and the mean value of the output signal peak to peak intensity, σ_0 and $\langle I_0\rangle$ those of the setup broadband noise without photons. Figure 2 shows the measured fluctuations δ_M^2 versus the inverse of the photon number for the 1 nm bandwidth filter and for a 100 nm bandwidth filter associated with a 1% transmission neutral density in order to collect the same photon number in both cases. As expected, the noise correction makes the fluctuation measurement coherent over the intensity range of the measurements.

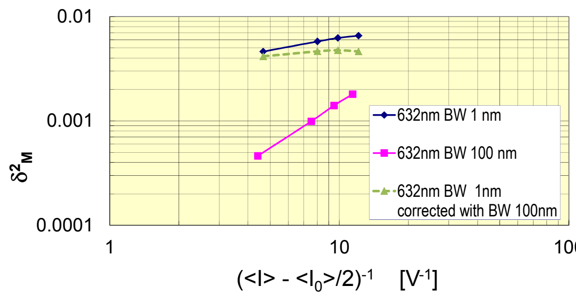

Figure 2: APD parasitic noise evaluation with a large bandwidth filter and fluctuation correction (8 mA 30 ps long bunch, BM).

First bunch length measurements were performed for the nominal value of 400 mA in 416 bunches, corresponding to 1 mA or 1.1 nC/bunch and 0.24 µW total power from the BM port through the 1.2 nm bandwidth filter centred at 632 nm. We observed that below this current, the corrected fluctuation value δ drops under the $\delta_{M[LBW]}$ correction term when using the 0.8 nm bandwidth filter.

In order to pursue measurements with lower bunch current produced in low-α optics [4], we investigated then the use of the 10 m long electromagnetic HU640 undulator [5] that enhances the number of photons by a factor of 20 in the visible range. The experimental setup was therefore installed at 28 m from the middle of the undulator and the coil currents were tuned to maximise the flux through our interferometric filters. Care has been taken to evaluate the $\delta_{M[LBW]}$ correction term taking into account the slight bunch length effect within the width of the undulator radiation on its fundamental wavelength.

TRANSVERSE COHERENCE CALCULATION

Transverse coherence sizes of both radiation sources have been evaluated using the SRW code [6]. The diffraction limited source size of a single electron has been determined in propagating the radiation wavefront until the experimental setup, taking into account the actual beamline aperture, and refocussing the radiation to a 1:1 image plane with an ideal lens (Fig. 3-b). Concerning the undulator calculation, particular attention has been paid to propagate the radiation at the effective experimental energy that is significantly shifted from the resonance energy of the undulator, because of the finite beamline aperture (Fig. 3-a). This phenomenon induces significant modification of the coherence spot shape (Fig. 3-c). In the image plane, we fitted the cuts horizontally and vertically at the centre of the spot with Gaussian curves, the widths of which are reported in Table 1.

On the other hand, rms radiation source sizes in the BM and in the middle of the HU640 long straight section have been checked on the machine using the LOCO code [7] and the steering error of the almost constant sized beam inside the long undulator was kept small enough to make its contribution to the effective source size negligible.

Table 1: Theoretical transverse rms source sizes, and coherence sizes at 632 nm, for nominal and low α lattices.

	σ_x µm	σ_{xc} µm	σ_z µm	σ_{zc} µm
Nominal α *Bending magnet*	87	70	23.1	152
$\alpha_{nom}/10$ *HU640 middle*	355	500	15.7	500

EXPERIMENTAL RESULTS

Fluctuation Range, Measurement Limitation

Depending on the bunch length and the filter bandwidth, our raw fluctuation rate ranged from 5 to 25% with a factor between the large band correction term $\delta_{M[LBW]}$ and the corrected value δ lying between 2 and 3. That means we could still decrease the measureable bunch current under the present 15 µA. A strong limitation of the method remains in the necessary number of data acquisitions to ensure satisfying accuracy, which is 3000 in our case.

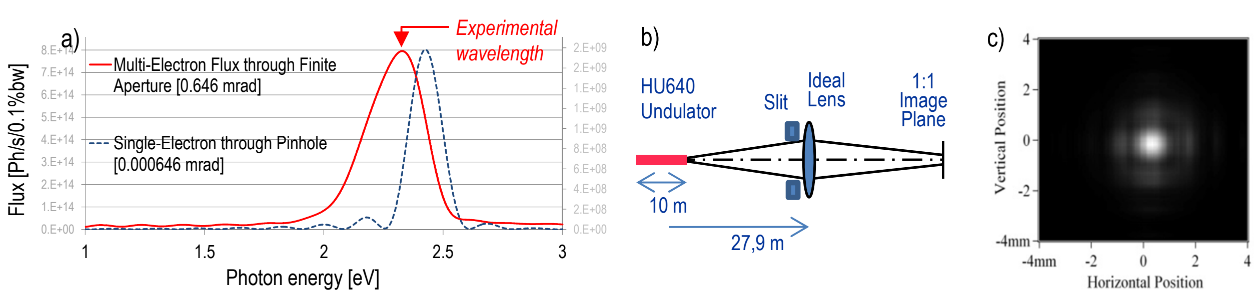

Figure 3: HU640 SRW calculation a) Undulator resonance energy (single-electron flux through pinhole) and experimental energy (multi-electron flux through finite aperture) b) Single-e radiation propagation scheme for coherence evaluation c) Intensity distribution in 1:1 image plane for the single-e radiation at the experimental energy.

Nominal Optics

First results from a 1.2 nm bandwidth filter centred at 632 nm using the BM radiation for a 2.5 MV RF voltage are presented in Table 2. A discrepancy of a few % is found when compared with the picosecond streak camera measurements, which is comparable to the statistical error.

Table 2: Bunch length measurements from the BM radiation for the nominal optics at V_{RF}=2.5 MV.

Bunch Current	mA	7.5	7.5	10.1
Physical apert. (H plane)	mrad	3.26	6.85	3.26
σ_t fluctuations (632 nm, 1.2 nm BW)	ps	29.7	31.8	39.7
σ_t streak camera	ps	31.1	31.1	38.3

Low-α Optics

Taking advantage of the low-α optics [4], we measured the picosecond range bunches using the HU640 radiation at different visible wavelengths. Figure 4 and 5 show comparison with both streak camera measurements, taking values integrated over 0.1 ms for the picosecond camera. The 514 nm filter results were found to be globally shifted by +20 % compared to the streak cameras', whereas the 632 and 532 nm filters show good agreement, even if they are also slightly shifted systematically (by +5 %). The tricky evaluation of the transverse mode numbers of the HU640 radiation may be involved, and could be improved in the future.

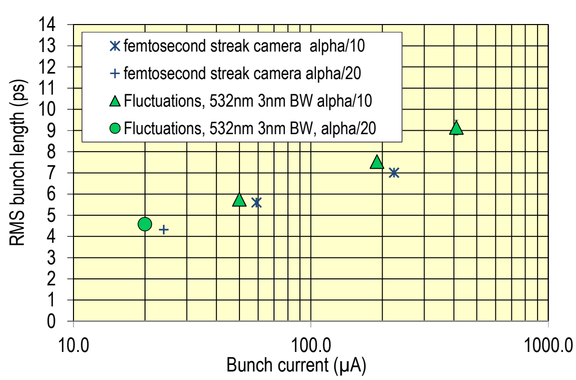

Figure 4: Bunch length measurements in low-α modes from HU640 radiation, V_{RF}=3.2 MV.

As a remark, the data quality at 400 µA (Fig. 4) has not been spoiled, despite the presence of microbunches observed with the THz radiation [8].

CONCLUSIONS AND FUTURE

Promising results have been found for length measurement of the low-α short bunch using the HU640 undulator radiation. In this case, the ratio between the width of the HU640's fundamental and the width of the random spikes emitted within the former, is about 1000. Therefore, we have shown the validity of the method in this range of spike number. In the near future, we intend to extend the tests towards lower values, about a few hundreds. Indeed, the low-α optics benefits now from the slow and fast orbit position feedbacks, and allows to decrease the α value in a stable way regarding the APD small effective area.

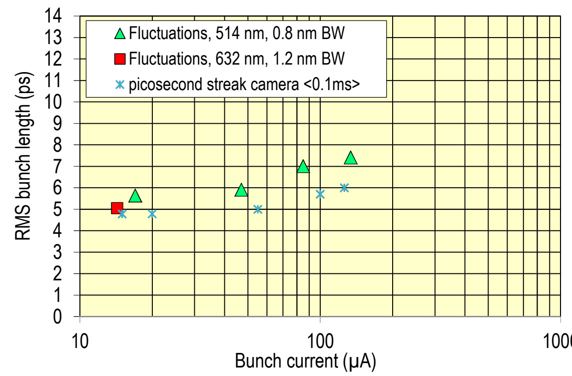

Figure 5: Bunch length measurements in low-α mode (α_{nom}/10) from HU640 radiation, V_{RF}=4 MV.

Measurement of even shorter bunch length in the femto-slicing operation could not be performed any more with the HU640 radiation because of a too low longitudinal mode number. For that reason, we intend to shift the wavelength to the soft X-ray and look for a new detector to be installed on a soft X-ray beam line at SOLEIL. For that bunch length range, a reasonable monochromator resolution will be sufficient. But again, the transverse mode number calculation will be a big issue.

ACKNOWLEDGMENTS

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