STREAK CAMERA MEASUREMENTS OF THE SOLEIL BUNCH LENGTH

M. Labat, M.E. Couprie, L. Cassinari, D. Pedeau, R. Nagaoka, SOLEIL, Saint-Aubin, France

Abstract

A double sweep streak camera (C5680, Hamamatsu) has been installed on the French third generation light source SOLEIL. The visible radiation of the diagnostics beam-line is used to study the longitudinal profile of the stored electron bunches. Measurements of single-bunch length as a function of various machine parameters such as RF cavity voltage and frequency, and beam current with a few picoseconds resolution are reported, and interpreted in terms of vacuum chamber impedance and beam stability.

INTRODUCTION

The third generation French light source SOLEIL has been recently inaugurated, and the machine commissioning with all the chambers of the insertion devices (except the invacuum devices) has been achieved. Among the 24 experimental beam lines foreseen, 9 are already opened. Synchrotron Radiation from infrared to hard x-rays ($>$ 8 keV) provided by bending magnets, undulators (U20, HU80 and HU256) and wigglers, is delivered for various type of experiments: micro-imaging, tomography, infrared to X-ray spectroscopy, electronic and magnetic studies [1]. The electrons are stored at an energy of 2.75 GeV, with an horizontal emittance of 3.74 nm.rad. Up to 300 mA can be stored presently in multibunch mode and 20 mA in single bunch mode. A Streak Camera has been installed in September 2006, for the study of the longitudinal profile of the electron beam either in stable or evolutive regimes.

STREAK CAMERA COMMISSIONING

Passing through a bending magnet, the 2.75 GeV electron beam emits light from visible to x-ray. The upper part of the radiation, in the visible range, is collected by an under vacuum aluminum flat mirror with a nickel coating. Using a periscope and a pair of mirrors, the beam is transported to the diagnostic hutch. The last four mirrors are all glass made, with an aluminum coating. On the diagnostic hutch optical table, a glass cube splits the beam in two lines, one sent to an imaging system for transverse size measurements [2] and the other to the entrance pinhole of the Streak Camera. A photocathode converts the light pulse into an electronic pulse, with similar longitudinal distribution.

A fast sweep, i.e. high frequency electric field, is applied at the ouput of the photocathode to deviate the electronic pulse in the vertical direction, allowing longitudinal projection of the distribution on a phosphore screen imaged by a CCD camera. Because the electronic of the device can't follow the 352 MHz RF frequency, the fast sweep is triggered at one fourth of this frequency, i.e. 88 MHz using a divider. A delay line (Hamamatsu C1097) is then used to adjust (with 0.5 ns steps) the timing position of the bunch on the fast "sweeping" sinusoid. Within one fast sweep period, four successive bunches are deflected (two with positive and two with negative fields). Four vertical scales are available, corresponding to four different sweeping ramps. Scale 1 enables a sweep of 149 ps, 2 of 694 ps, 3 of 1293 ps, and 4 of 1883 ps (widest possible scan with a 88 MHz sweep frequency). A second slow sweep, i.e. lower frequency electric field is simultaneously applied in the horizontal direction. The bunch profiles are juxtaposed (starting from left) according to their arrival time, allowing to follow their evolution. The slow sweep (as well as the CCD camera) are triggered by the storage ring master clock at 846 kHz. The time delay in between slow sweep and camera acquisition can be adjusted with a Stanford, DG535. The horizontal scales range from 100 ns to 1 s.

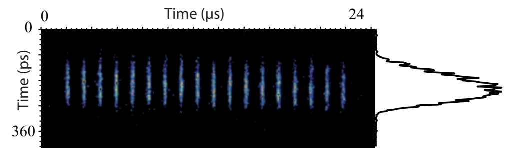

Figure 1: Evolution in time of the longitudnial bunch profil. Streak Camera measurement. V_{RF}= 2 MV. Horizontal scale: 20 μs, Vertical scale: 800 ps. Single bunch mode. I=12.6 mA. Data of 15/12/2006.

The images recorded by the CCD camera are further analyzed to provide the desired information on the longitudinal distribution of the electron beam using momenta calculations. A typical image is given in Figure 1.

The resolution of the Streak Camera depends on the spatial resolution and the vertical scale: $Res_T = \frac{Spot\ size(pixels)}{Total\ Number\ of\ pixels} \times Vertical\ scale(ps)$. The spatial resolution is measured using the FOCUS mode (see Figure 2), i.e. without sweep. With an entrance hole of 30 μm (resp. 100 μm), the spot size is 8.7 mm FWHM (resp. 16.3 mm FWHM), corresponding to 5 pixels (resp. 9 pixels). Since the expected resolution is higher with 30 μm, its use became systematic. Highest resolution of 1.5 ps is reached with scale 1 and 30 μm entrance hole. But scale 2 is mostly usually used, suiting better to the length to be measured at SOLEIL: in this case, the resolution is 6.8 ps.

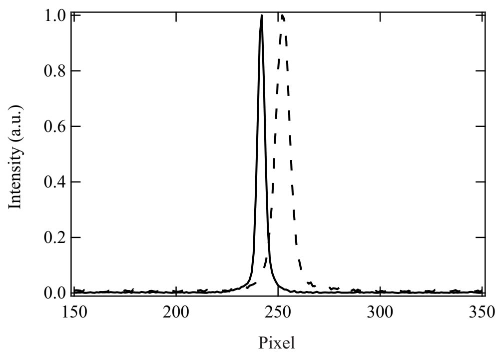

Figure 2: Streak Camera spatial resolution measurement. Vertical line profile of the Streak Camera image of the bunch radiation in the FOCUS mode. Entrance hole diameter: 30 μm (Continuous line), and 100 μm (Dashed line).

BUNCH LENGTH MEASUREMENT AT ZERO CURRENT

The bunch length has been measured at very low current (below 0.2 mA) in two different operating modes: single bunch and multibunch (with 28 bunches injected). According to theory [3], the expected bunch length in a storage ring at zero current σ_{e0} is defined as:

$$\sigma_{e0} = \frac{\alpha}{2\pi f_S}\sigma_\gamma, \quad (1)$$

with α the momentum compaction factor, f_S the synchrotron frequency which depends on the RF voltage, and σ_γ the natural energy spread. A single bunch tracking code [4] provides estimation of the bunch length at zero current using relation 1.

The theoretical and experimental results are presented Figure 3. The measured bunch length in single bunch mode is higher by 1.5 to 4.5 ps than the value given by (1), and the smaller the RF voltage, the smaller the discrepancy. At 1.2 MV, it is only 1.5 ps. The measured bunch length at zero current with 28 bunches stored leads to shorter values, and therefore closer to the value given by (1): the discrepancy remains below 1.6 ps at 2 and 2.8 MV. The difference observed between single bunch and 28 bunches modes may be partially due to the fact that distinct horizontal scales were used: 5 ms for 28 bunches operation and 100 ms for single bunch operation. The difference observed between theory and experiment could also be explained by the measurement conditions: no measurements were performed below 0.11 mA.

BUNCH LENGTHENING

Bunch lengthening at SOLEIL is studied as a function of the beam current, for different RF voltage values. As illustrated in Figure 4, the bunch length increases with the current, and the higher the RF voltage, the shorter the bunch length. In addition, because of the vacuum chamber

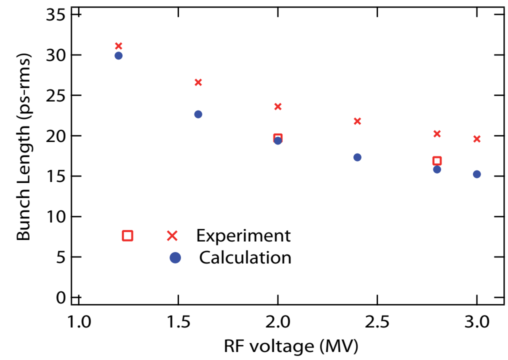

Figure 3: Bunch length at zero current as a function of the RF voltage. Experimental values in (□) multibunch mode (28 bunches, average over 5 ms), (×) Single bunch mode (average over 100 ms). (•) Calculated values using Equation (1).

impedance, the longitudinal profile becomes more asymetrical at high current. A pinhole camera enables simultaneous measurement of the energy spread. It is found constant on this range of current. The lengthening may mainly be due to impedance effects.

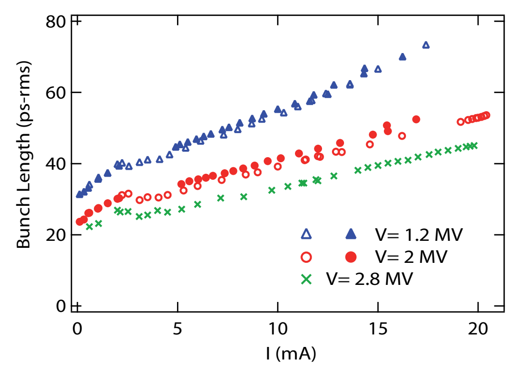

Figure 4: Bunch length measured versus current. (○,△,×) before (February 2007), and (•,▲) after (April 2007) installation of an additionnal insertion device: U20. Single bunch mode. Streak Camera measurement.

Figure 4 presents two series of bunch length values versus current with 1.2 and 2 MV, which are found in very good agreement. In between the two measurements (February and April 2007), an additionnal in vacuum insertion device, an U20, was installed with its chamber without effect on the bunch lengthening. Such results validates the use of RF fingers for impedance matching at the entrance and output of the undulator.

The lengthening is simulated using the tracking code (see Figure 5). At non zero current, the simulation uses an impedance evaluated taking into acount the elements along the ring such as BPMs, the dimension of the vacuum chamber as well as its main discontinuities and inside rugosity. The influence of the NEG deposition on the wall of aluminium vacuum chambers is not yet considered. The experimental lengthening with respect to the zero current

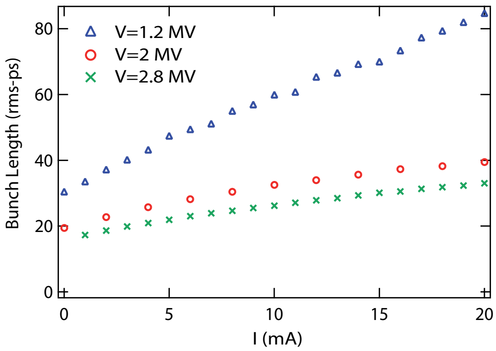

Figure 5: Bunch length calculated versus current using the tracking code.

value between 0 and 20 mA is found in good agreement with the simulation. At 1.2 MV (resp. 2 and 2.8 MV) the simulated lengthening is 155 % (resp. 104 and 92 %) and 114 % (resp. 103 and 100 %) experimentally. The relative enhancements are similar. In addition, both experiment and simulation agree on the following behaviour: the higher the RF voltage, the slower the lengthening. Finally, operation at 1.2 MV clearly leads to larger enhancement. A dramatic reduction of the lifetime was simultaneously observed: the dynamic acceptance limit was reached.

The remaining discrepancies may be due to some imperfections in the modeling of the impedance in the tracking code. Further investigations for impedance measurement are foreseen.

LONGITUDINAL BEAM STABILITY

Figure 6 shows a high level of longitudinal stability in the multibunch (1/4) mode. It results from SOLEIL choice of adopting superconducting cavities (two within one cryomodule). Such technique supresses the excitation of the beam by Higher Order Modes (HOM).

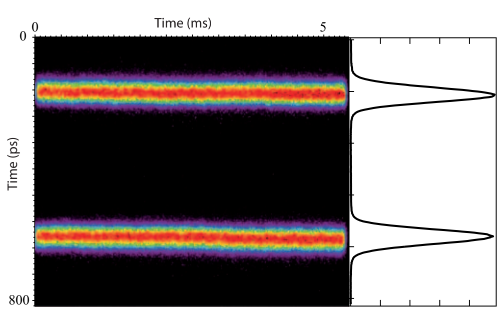

Figure 6: Illustration of the longitudinal stability of the beam in mutlibunch (one fourth of the RF buckets are filled) mode. Streak camera image and associated vertical profile. I=65mA. Data from 09/2006.

Nevertheless, longitudinal beam instabilities can be obtained with external excitation of the beam. In the example presented in Figure 7, longitudinal oscillations with a period of 1.2 ms are observed. Those instabilities result from a sudden change of the RF voltage: from 2 to 1.5 MV. Similar oscillations were observed simultaneously on the BPMs.

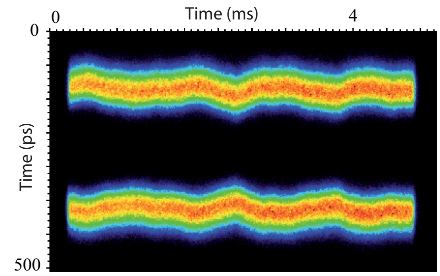

Figure 7: Evolution in time of the longitudinal bunch profil. V_{RF}= 1.5 MV. Multibunch mode with 28 bunches. I=156 mA. Streak Camera measurement. Horizontal scale: 5 ms, Vertical scale: 800 ps. Data of 04/10/2006.

CONCLUSION

The SOLEIL Streak Camera enables electron beam longitudinal studies. The first issue was bunch length measurement under various parameters such as current and RF voltage. It provides an evaluation of the light pulse duration delivered to the users, with a precision below 6.8 ps, whatever the operating mode (single or multibunch). The device also allows dynamical studies and validated the longitudinal stability of the beam thanks to the superconducting cavities. Finally, further studies are undergoing to investigate the ring impedance via phase shift measurements. Those might help refining the impedance model by confirming that the NEG deposition does not influence its real part.

ACKNOWLEDGMENTS

The authors would like to thank J. Roux (Hamatsu France) and J.C. Denard for their support.

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