DIAMOND OPTICAL DIAGNOSTICS: FIRST STREAK CAMERA MEASUREMENTS

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Abstract

We present in this paper the first measurements of the electron bunch profile with a streak camera during phase I of the commissioning of Diamond. We recorded the bunch profile during injection. Phase and energy offset were observed. Moreover, estimates of the bunch length at injection and of the stored beam are measured. Finally, we derived the minimum charge in a single bunch to be measurable with the streak camera based on a comparison between bench measurements and synchrotron radiation measurements.

INTRODUCTION

The Diamond synchrotron light source is the UK 3$^{\rm rd}$-generation light source [1]. During phase I of the storage ring commissioning, we used our dual sweep streak camera to measure the longitudinal profile of the electron bunches injected and stored for the very first times in the Diamond storage ring. A streak camera is not an essential tool for the commissioning of a storage ring. However, as this is the only known instrument that can measure the profile of a picoseconds electron bunch, it may be used to characterise essential features of the ring, e.g. the vacuum chamber impedance [2, 3, 4], or quantities such as bunch length, energy spread, energy and phase offsets at injection [5]. In particular, a good control of the electron phase and energy is important to optimise injection efficiency and a streak camera can be used as a tool for this.

In this paper we present our first measurements of the Diamond electron beam with our streak camera. We observe the beam at injection and measure bunch length of the stored beam. Finally, by comparing these first results with previous measurements from bench tests, we discuss the performance and limits of our streak camera.

STREAK CAMERA MEASUREMENTS

Phase I commissioning of Diamond storage ring has been done with electrons at 700 MeV instead of the nominal energy at 3 GeV, due to lack of cooling water [1]. A comparison of the parameters of the storage ring for both cases is summarised in table 1. A set of optical and X-ray diagnostics has been developed and installed to measure the sixth-dimensional phase-space of the stored electrons [6]. In particular, for the electron bunch profile measurement we use the Optronis[1] dual sweep streak camera (SC). A SC converts the time structure of a photon pulses into linear deflection along two axis of a screen. To this end, the SC is composed of a photocathode, a streak tube that accelerates and focuses the generated electrons, horizontal and vertical electrodes that deflect the electrons, and a phosphor screen. This screen, which is 18.6×13.8 mm^2 in our case, is then imaged by an intensified CCD. A 'fast' and a 'slow' unit drive the two electrodes:

Table 1: Nominal and phase I commissioning parameters of the Diamond storage ring

Parameter	**Nominal**	**Phase I**
Beam energy, E (Gev)	3	0.7
Ring circumference (m)	561.6	
Harmonic number, h	936	
RF frequency, ν_{RF} (MHz)	499.654	
Revolution frequency, f_0 (kHz)	533.818	
RF voltage, V_{RF} (kV)	3100	20-100
Energy loss per turn, U_0 (keV)	1000	3
Synchrotron frequency, f_s (kHz)	2.6	0.5 - 1.6
Momentum compaction factor, α_c	$1.7 \cdot 10^{-4}$	$3 \cdot 10^{-4}$
Synchrotron damping time, τ_s (ms)	5.6	440
Relative energy spread, σ_ϵ	$9 \cdot 10^{-4}$	
Bunch length (r.m.s), σ_τ (ps)	10	24

- The fast sweep can be generated by a single sweep unit that ranges from 10 ps/mm to 1 ns/mm which can be triggered with up to 2.5 kHz, or it can be generated by a synchroscan unit which sweeps continuously at 250 MHz with sweep ranges from 10 ps/mm to 50 ps/mm. In our case, for the commissioning we used the synchroscan unit, which is tuned and phase locked at half of the RF frequency (ν_{RF}).

- Two different slow triggered units provide sweep speeds from 660 ps/mm to 5 ms/mm. We triggered the slow sweep synchronised with the injection at 5 Hz. The sweep ranges we used were from 1 μs/mm to resolve individual turns on the images to 5 ms/mm to record the beam dynamics after injection.

The synchrotron radiation from a bending magnet (BM1) is focussed on the SC using a system of mirrors to transport the light from the storage ring tunnel into a optical diagnostics cabin on the experimental hall floor. The obtained SC images contains two axis of temporal information: On the fast axis the profile of the photon pulses can be observed, and on the slow axis the successive pulses in a train. As the time structure of the synchrotron radiation is generated by the time structure of the electron beam in the storage ring, the streak camera can reveal this structure.

[1] http://www.optronis.com

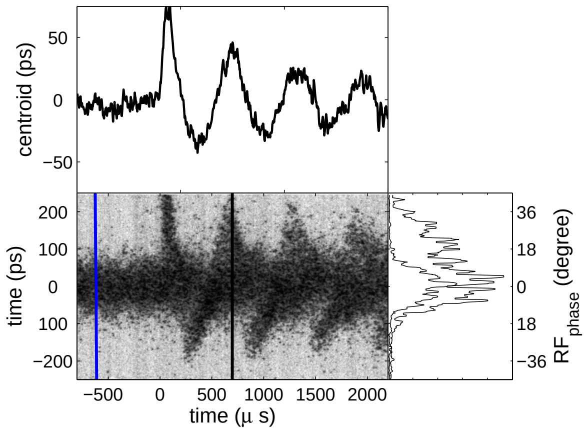

Figure 1: Streak camera image showing the beam at injection. The energy and phase are mismatched at injection. The top figure shows the centroid of the beam distribution, which oscillates at the synchrotron frequency ($f_S \approx 1.6$ kHz). The right-hand side graph shows the electron bunch distributions at 610 μs before the injection and 700 μs after injection.

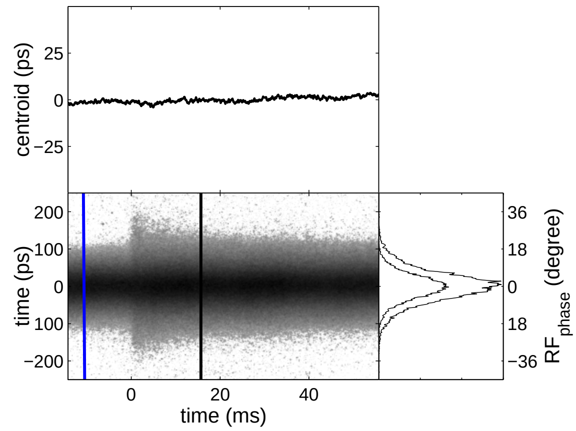

Figure 2: Matched energy and phase at injection, and stored beam. The bunch length is 85 ps shortly after injection, and 70 ps just before injection (that is after 200 ms), which shows that the beam is still oscillating then.

First Day Measurements

The very early stored beam at Diamond has been measured with the SC. First, we recorded the beam at injection, as seen in figure 1. The figure shows the injected beam at 0 μs on the image scale, followed by large oscillations of the centroid - and the higher order moments - of the bunch distribution at the synchrotron frequency. Before the injection, one can observe the previously injected beam which has remaining but damped oscillations. After adjusting the RF frequency and phase, the SC image (figure 2) shows that these oscillations are reduced, as expected from theoretical and computer simulation studies of the injection process [7, 8, 9].

The longitudinal phase oscillations of the beam can also be measured with the signal from the electron beam position monitors (EBPM) as these are sampling the beam at a frequency that is phase locked with the RF frequency. As a result, the phase of the BPM signal measures the phase of the electrons. Figure 3 shows such a measurement immediately after injection. It shows, similarly to the streak camera that the beam is injected with phase and probably energy offset. So both the EBPMs and SC can be used as complementary tools for injection optimisation. As EBPMs measure the centroid of the bunches distribution, they can be used for a rapid optimisation of injection. However, the bunch distribution can only be measured with the SC, which can be used for advanced optimisation of injection. We plan to investigate these features more closely in the next phase of commissioning and and will focus in particular on a comparison of the two measurements. For example, one may note that the two centroid oscillations have different frequencies. The reason for this is that they have not been taken at the same time and during the commissioning the RF voltage and has been changed frequently. Consequently, the synchrotron frequency varied, which explains the difference between the synchrotron frequency measurement with the EBPMs and with the SC several hours later.

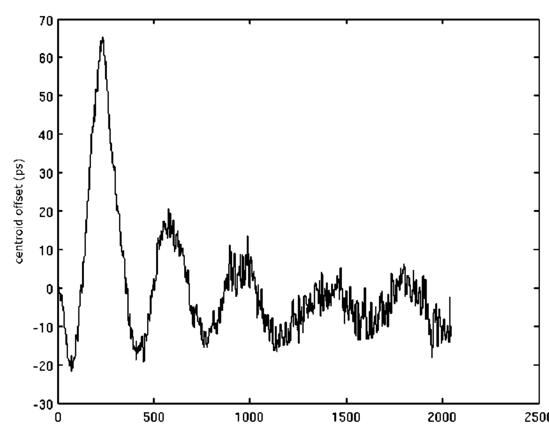

Figure 3: Beam longitudinal phase oscillation at 1.4 kHz measured with the phase of the complex signal from the EBPMs.

Figure 4 shows the average profile of several thousand turns of the stored beam at 200 μA, extracted from a SC image. We note that intensity of the single pulses of the synchrotron radiation was not enough to permit single pulse profile measurement. However, the beam is stable, and the Gaussian fit gives the r.m.s bunch length $\sigma_\tau = 24$ ps which is very close to the expected value. Expression 1 gives the nominal bunch length

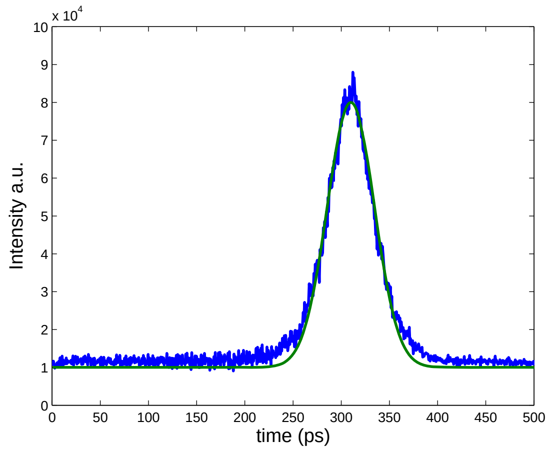

Figure 4: Profile of the stored beam, and Gaussian fit. The bunch length is measured at $\sigma_{r.m.s} \approx 24$ ps.

$$\sigma_\tau = \frac{\alpha_c}{\Omega_s}\sigma_\epsilon \tag{1}$$

where α_c is the momentum compaction factor, $\Omega_s = 2\pi\nu_{RF}$ and σ_ϵ is the relative energy spread.

With $\alpha_c \approx 0.0003$, $\nu_{RF} \approx 1.4$ kHz, and $\sigma_\tau \approx 24$ ps, the energy spread is estimated to be $\sigma_\epsilon \approx 7 \times 10^{-4}$. Compared to predicted value of $\approx 9 \times 10^{-4}$ this can be seen as good agreement given the uncertainty on the momentum compaction factor and on the RF voltage.

Detection Level And Single Bunch Measurement

SC measurements of a short pulse laser diode (15 ps (r.m.s), 300 mW peak) showed that the streak camera can reliably image individual single pulses of 10 pJ. The synchrotron radiation is collected from the source point (second bending magnet after injection) and transported over 25 m through a series of 2” mirrors at 45 degrees, so that we can focuss ≈1 mrad of visible (350-650 nm) synchrotron radiation on the SC. During the commissioning, we measured an accumulated current of 2 mA while continuously injecting, and a stored current at 0.2 mA. The full injected train had 100 bunches. Therefore, the energy of a individual single pulse varied between 40 fJ and 400 fJ. This is below the experimentally found level at which the SC can give an accurate measure of a single pulse profile. As a result, the full train could be observed but no single bunches.

In turn, we can empirically fix the limit of observation of a single bunch to ≈1 nC/bunch (or ≈0.5 mA/bunch) at 3 GeV. With such a current per bunch, accurate bunch profiles can be measured. This would allow to characterise the vacuum chamber impedance, using for example known analytical solutions [3, 10], which give the bunch longitudinal profile as function of the current taking into account the ring impedance as a parameter.

CONCLUDING REMARKS

Bunch length measurements using a SC have been performed at the very early stage of Diamond commissioning. It confirms our prediction on the optics of the machine, and the expected energy spread. Furthermore, this early set of measurements shows how the SC can be used in the next phase of the commissioning, in particular for the fine tuning of the injection. The current threshold per bunch at which single bunch profile can be measured has also been derived and is set to be around 1 nC/bunch. Finally, the current per bunch was too low to allow a reliable measurement of the vacuum chamber impedance using the bunch profile but we are confident to be able to perform such a measurement at 3 GeV and as function of the current larger than 1 nC/bunch.

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