THE ELETTRA STREAK CAMERA: SYSTEM SET-UP AND FIRST RESULTS

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Abstract

At ELETTRA, a Streak Camera system has been installed and tested. The bunch length is a significant machine parameter to measure, as it allows a direct derivation of fundamental machine characteristics, like its broadband impedance. At ELETTRA the Light from a Storage Ring Dipole is delivered through an optical system to an Optical Laboratory where it can be observed and analysed.

The Streak Camera is equipped with different time-bases, allowing both single sweep and dual sweep operation modes, including the Synchroscan mode. The Synchroscan frequency equal to 250 MHz, which is half of the ELETTRA RF frequency, allows the acquisition of consecutive bunches, 2ns apart. To fully exploit the performances of the Streak Camera, an optical path has been arranged which includes a fast opto-electronic shutter. By doing so, the optical power deposited on the photo-cathode is reduced in the different ELETTRA fillings.

1 INTRODUCTION

The bunch length measurement on Storage Rings has to be non-destructive; therefore a classical approach to the problem is to measure the length of the Synchrotron Light Pulses generated by the transversely deflected electrons, as it happens in the Bending magnets (Dipoles).

This is correct as the light pulses propagating from the source point to the measurement point preserve, in their longitudinal profile, the electron longitudinal distribution, that is the Bunch Length (σ_B).

In third generation light sources, this measurement is critical due both to the very short duration of the synchrotron light pulses, which lies in the range of Pico-seconds, and to the low energy per pulse available.

Streak Cameras are routinely used as powerful diagnostics tools in both linear (usually observing Transition Radiation rather than Synchrotron Radiation) and circular accelerators.

The main features of a Streak Camera are:

- Pico-second resolution, even in Single Shot
- very high (100s of MHz) repetition rate of the fast sweeps with dual-sweep "Synchroscan" mode
- high sensitivity, thanks to built-in photo multiplier

2 SYSTEM SET-UP

At ELETTRA the Light from a Storage Ring Dipole [1] is delivered through an optical system to an Optical Laboratory: the first vacuum mirror allows only the Visible and near-UV part of the Synchrotron Light Spectrum to be used. Beside a Transverse Profile Monitor system [1], other instruments [2, 3 and 4] have been installed and tested. Bunch Length measurements have been already performed [5], both with a Streak Camera and an Ultra-Fast Photodiode.

At ELETTRA, a Streak Camera (SC), specifically manufactured by Photonetics [6], has been recently installed and successfully tested [7,8].

The basic operating principle of a SC is a time-to-space conversion of ultra-fast optical events. The incoming photons are converted into electrons by a photo cathode. The emitted electrons are accelerated and deflected by a high-voltage fast ramp applied to deflection electrodes.

As a result, electrons are streaked out on the back-end phosphor screen creating a strip, whose length is proportional to the duration of the photon bunch. The image formed on the phosphor screen is amplified with a Micro Channel Plate (MCP) image intensifier and acquired by a CCD camera.

The ELETTRA SC is equipped with different sweep Units [9], which allow the following operation modes:

- single sweep, providing <2ps $_{FWHM}$ resolution
- dual sweep, with Synchroscan Unit at 250MHz

Synchroscan is a deflection technique, widely used in streak cameras, where the high-voltage deflection is driven by a sinusoid rather than a saw-tooth ramp. Thanks to the narrow-band deflection signal, the linearity of the high-voltage deflection amplifier is more easily achieved than in a wide-band amplifier, which is needed for a saw-tooth linear deflection.

The Single sweep unit (FTSU-1) provides the following full-screen deflections: 176ps, 441ps, 882ps, 1.7ns, 4.4ns, 8.8ns and 17.6ns, with <2ps$_{FWHM}$ resolution.

The Synchroscan unit (FSSU-1) operates at a frequency of 250MHz (res.=3.2ps$_{FWHM}$). The Secondary sweep units (FTSU-2 and STSU-2), used for vertically displacing successive Synchroscan traces, can cover the range from 9.15ns to 69.35ms.

3 THE OPTICAL PATH

The optical path (partial view shown in fig.1) performs the following operations on the synchrotron light:

1. deflection and focusing onto the SC input pin-hole (with 50, 100 or 200μm diameter)
2. band-pass (λ=500nm) filtering and attenuation
3. shutter for interlock purposes
4. optical power reduction

The reduction of the optical power on the time scales typical of a SC is not a straightforward task.

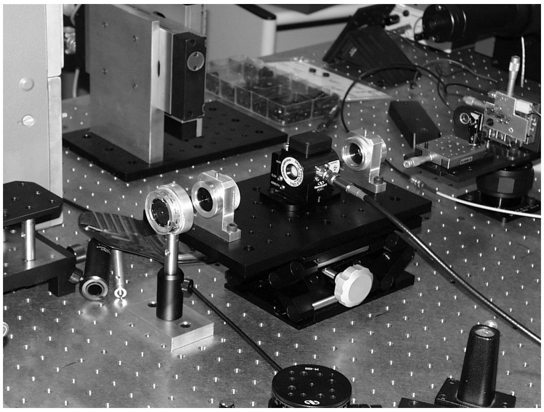

Fig. 1: A partial view of the Optical Path to the SC showing the Pockels Cell system.

The timings needed to achieve an effective reduction are reported in Table 1. Furthermore, the shutter operation has to be synchronous with the light pulses.

ON/OFF ratio	>100	a. u.
T_{ON} ; T_{OFF}	<5	ns
$GATE_{MIN}$	100	ns
$GATE_{MAX}$	50	ms
$f_{REP\ MIN}$	1	Hz
$f_{REP\ MAX}$	1	kHz

Table 1: fast shutter parameter list.

To meet the requirements, a Pockels Cell opto-electronic shutter [10] has been adopted.

3.1 Pockels Cell operation

A Pockels Cell [11] introduces a rotation (typically by 90^o) on the polarisation axis of the incident wave, upon the application of an external electric field E_T. By placing two polarisers, rotated by 90^o, respectively up-stream and down-stream the Pockels Cell, such a system acts as a fast shutter, driven by E_T.

To operate the system, a careful alignment of its elements is required. Furthermore, two pinholes are necessary to remove unwanted spots, which generate inside the system due to spurious reflections.

By carefully aligning all these elements, the ON/OFF ratio of the light can be maximised, while keeping a good transmission through the shutter.

The low-frequency trigger pulses, synchronous to the synchrotron light pulses, for the Pockels Cell high voltage (V_p=2.5kV) driver [12] are generated by the SC timing system. The duration of the trigger pulse (GATE) can be varied according to the SC operation mode and to the synchrotron light time structure.

3.2 Pockels Cell characterisation

The correct operation of the Pockels Cell shutter has been checked at low repetition rates (1 Hz), with long opening times (5ms) for direct eye-observation, while at higher repetition rates, up to 2kHz with the nominal opening time (100ns to 10µs) a wide-band (1GHz) photodiode has been used.

At the highest repetition rates (>2KHz), the closing of the Cell begins to show a ringing (fig.2), which is believed to be due to an opto-acoustic phenomenon induced by the piezoelectric effect. A similar effect has been observed by other authors [13].

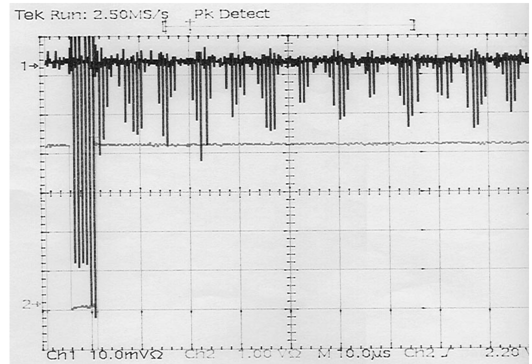

Fig. 2: Pockels Cell ringing, hor. scale = 10 µs/div.

With long Gates (>50 µs), an amplitude modulation effect of the transmitted light (observed with a laser on the photodiode and with the synchrotron light on the Streak Camera) shows up. It has to be taken into account for accurate beam stability observations.

The final check on the shutter operation has been performed "live" with the SC sweeping: in fig.3 the Pockels Cell effect is shown on a Synchroscan acquisition.

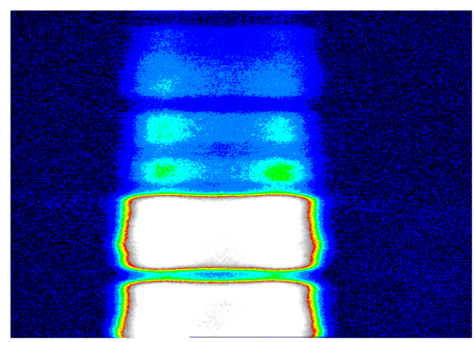

Fig.3: Pockels Cell effect on a Synchroscan acquisition. HOR.=441ps, VERT.=3.46•s. (full screen).

The Pockels Cell shutter is now currently used to improve the photo cathode lifetime; typical operating conditions are: f_{REP} < 20Hz, 200ns < GATE < 20µs. For stability studies, on long time scales, it may be removed.

4 THE SYNCHROSCAN OPERATION

The main advantage of Synchroscan deflection, associated to a dual-sweep streak tube, is to provide picosecond resolution at a very high repetition rate, typically less than 150MHz. To fully exploit this technique, both positive and negative slopes of the sinusoid are used. For ELETTRA, a dedicated streak tube has been developed by Photek [14]: this unit provides stable Synchroscan operation at 250MHz, with $3.2ps_{FWHM}$ resolution.

For the f_{RF} for ELETTRA is 499.654MHz and this feature has led to the unique possibility of observing consecutive bunches of a multi-bunch beam. Another outstanding feature of the ELETTRA SC is that the fastest sweep on the orthogonal slow axis is equal to 9.14ns. This feature allows the observation of a small number of consecutive bunches; five are shown in fig. 4 (acquisition in average mode). Filling MB, 80%, I=220mA, E=1GeV.

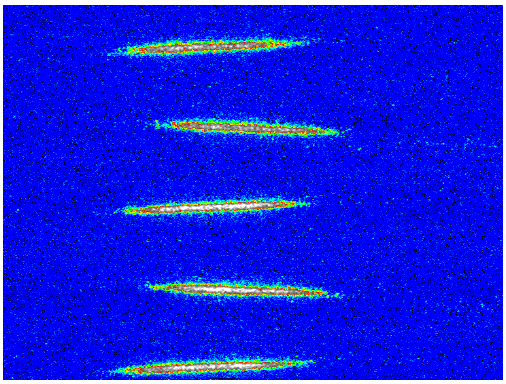

Fig. 4: Synchroscan acquisition at 250 MHz. Scales (full screen): HOR.=441ps, VERT.=9.14ns.

Due to the longitudinal coupled-bunch instabilities, present at the time of measurement, and also because of the average acquisition mode, each bunch image is much longer than its natural value. The operation of Synchroscan sweeping is made evident by the slope of the even and odd bunches.

5 THE STREAK CAMERA LOCAL CONTROL SYSTEM

The ELETTRA SC has been delivered with a user-friendly interface (Optoscope [9]) running on a desktop Personal Computer (PC) under Win95®. Through this graphical interface it is possible to control:

- The sweep units and MCP intensifier gain
- The status of the shutter
- The image acquisition and analysis processes
- The storage and export of the images

The SC and the PC are linked via a standard Serial line. The image acquisition and analysis functions are implemented on a powerful Image Analysis board [15], with a TMS 320C40 DSP chip on-board. A push-button keypad is also provided for direct control of the SC.

5.1 The Local Control system

It is based on two Personal Computers:

1. the desktop PC, delivered with the Streak Camera
2. a VXI-PC, developed in-house

The following functions are integrated:

- control over SC sweep units, MCP and shutter
- acquisition and analysis of the SC output images
- control on the timing system used to generate the appropriate trigger pulses and Synchroscan signal
- control on the safety and interlock functions
- generation of the video signal for the Control Room

The main reason for using two PCs is the cutting of development times, which has been achieved thanks to the full integration of the desktop PC in the Local Control System, leaving the only internal developments to be the timing and interlock boards.

5.2 The timing/interlock control computer

The timing and interlock functions have been implemented on VME/VXI custom boards, on a VXI crate with an Intel-based VME CPU. This solution provides the typical VXI hardware environment (EMI/EMC, ease of integrating custom boards, power supplies) with the Win95® OS software environment. The safety-critical interlock functions are hardware implemented on a custom board and use the software only for signalling its internal status.

5.2.1 The CPU of the VXI PC

Different CPU boards and operating systems have been tested. A PCVXI-745 (486 µP @ 66MHz) board, from National Instruments running LabView® under Win95®, has been tested first [16]. A Eurocom-128 (Pentium®100) from Eltec, running Linux has been used due to the temporary unavailability of the PCVXI-745. The final solution will adopt a VME-7591-941 board (Pentium®233_{MMX}) from VMIC, running either Win95® or Linux. This was the only board with the PMC [17] connector used for the PMC frame grabber (Control Room video signal generation).

The Control Room monitor will provide the operator with a “live” image of the SC output together with the relevant data (time axis, computed σ_B, peak-to-peak amplitude of longitudinal oscillations etc.).

5.2.2 The timing system

The timing system generates the:

- Trigger signal for FTSU-1, FTSU-2 and STSU-2
- Synchroscan signal for FSSU-1
- Pockels Cell GATE

These signals have to be synchronous to the light pulses, with a minimum jitter (< 3ps). To have the light pulse exactly in the middle of a fast sweep, the trigger to FTSU-1 has to be adjustable in 2ns steps, for one revolution period (864ns at ELETTRA), with a fine adjustment in 10ps steps. The repetition frequency ranges from 2.5kHz (FTSU-1 average acquisition) down to 1Hz (slowest sweep of STSU-2).

The Synchroscan signal is a pure sinusoid (0dBm), derived directly from the RF accelerating voltage. Thanks to a loan from E. Rossa at CERN, we are presently using the CERN Pico timing [18] VME board to obtain the divide-by-2 ($f_{RF/2}$) version of the RF and the Turn Clock signal (f_{RF} divided-by-(432x20)=57.83kHz).

At the time of writing, a new RF programmable-divider board has been developed, using the same

ECLinPS® Motorola family [19]. Measured jitter is <2ps: it could replace, in the future, the Picotiming module.

A second auxiliary board [20] is presently under development and will perform:

- further programmable divisions and level conditioning on the TCK to obtain the required low-frequency Trigger signal
- filtering and amplification are applied to the $f_{RF/2}$ to obtain the sinusoid for the Synchroscan signal
- Pockels Cell GATE generation
- intensity loop control (on-board 16-bit μP [21])
- interlock function

5.2.3 The interlock system

The interlock system checks the following conditions:

- light intensity level trespass (detected by means of a photodiode with hardware threshold and comparator)
- absence of the f_{RF} and Trigger signals

These alarm conditions are OR-ed together so that, as soon as any of these become true, the shutter to the SC is closed and a message sent to the Local Control Panel.

5.3 The Local Control Panel

At present no remote control will be delivered to the Control Room. The reasons for this are:

- precautions in using the photo cathode and MCP
- the Storage Ring FEL [22] control will be close to the SC Optical Laboratory
- development cost and time: to safely remotise the SC control, a non-negligible effort is required

A Control Panel will be developed on the desktop PC using the CVI® (National Instruments) development environment [23]. This panel will integrate the functions available on both PCs, using links both to the Optodll.dll (image analysis library provided by Photonetics) and to the VXI-PC by using CVI built-in TCP client-server library functions. This Control panel will also enable the non-expert user to safely use the SC.

6 MEASUREMENT RESULTS

The SC was delivered to Sincrotrone at the end of November, last year. Since then, in a two-month period, full performance has been achieved.

The goals for these commissioning tests were:

- to acquire single shot images, both with single-bunch (SB) and multi-bunch (MB) beams
- to operate the Synchroscan at 250 MHz
- to test the fast opto-electronic shutter with the SC

The SC has been also operated without the Pockels Cell, mainly on slow sweeps (10-50 ms) where the effect of optical power reduction, introduced by the fast shutter, is minimum.

Since February, during dedicated shifts, the first measurements of the ELETTRA beam were taken under different machine conditions, multi-bunch and single-bunch.

6.1 Preliminary tests of the SC system

The operation of the peripheral devices and the SC compliance to the specifications has been verified.

The jitter of the Trigger pulse to the SC has been measured to be less than 3ps, with the repetition frequency varying from 2Hz up to 2kHz.

The spectral purity and the level (0dBm) of the 250 MHz Synchroscan signal have been checked.

The synchronous opening of the Pockels Cell has been checked by directly cutting the light of the beam, with a (T_{OFF}-T_{ON}) time down to few nanoseconds.

Synchroscan has been operated at 250 MHz, although ELETTRA σ_B (>10ps) doesn't allow a direct verification of the Streak Camera time resolution (<3.2ps_{FWHM}).

6.1.2 Single Shot measurements

In a single shot measurement the light pulse is acquired with a single trigger event, without any possible averaging effect. In a Synchrotron light source, the worse case for single shot acquisition is with MB beams. The bunch charge may be some 10-100 time less than SB beam. Single Shot acquisitions were compared to averaged acquisitions and the negligible differences confirmed the jitter-free operation of the whole Streak Camera system.

6.2 Multi-bunch (MB) measurements

At ELETTRA, MB mode is the standard User Mode: 345 buckets filled, out of a total of 432 (80%). The injection current is 300mA, @2GeV. The coupled-bunch longitudinal instabilities are cured by tuning the RF cavity temperatures and by checking the beam spectrum.

A direct observation of these longitudinal oscillations is now possible, as shown inf fig.5. At 2.4GeV a more stable beam is observed compared to 2GeV.

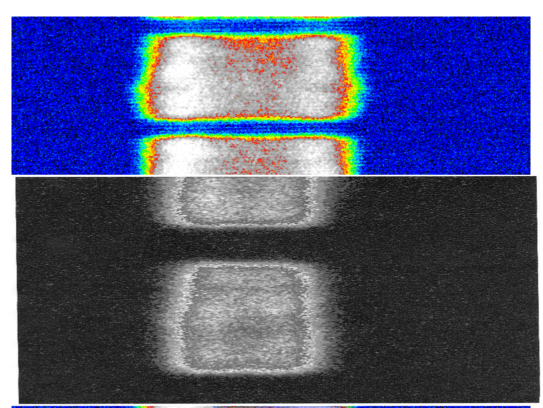

Fig.5: comparison of beams at 2.0GeV (upper half) and 2.4GeV(lower half) with two Synchroscan acquisitions.

6.3 Single-bunch (SB) measurements

In SB mode, two different fillings were measured:

- a single bunch (T_{REV} = 846ns)

- 4 bunches, evenly spaced, T_{BUNCH}=216ns

New long time scale information was obtained on beam stability. These studies are an important factor in understanding operation of the Storage Ring (SR) Free Electron Laser (FEL) [22].

The σ_B vs. current was measured (0 to 30mA in single bunch; 0 to 100mA in 4-bunch filling). In fig.6, single bunch profiles, at different currents, are shown. These profiles show that the electron distribution is close to a Gaussian distribution, as predicted by the theory.

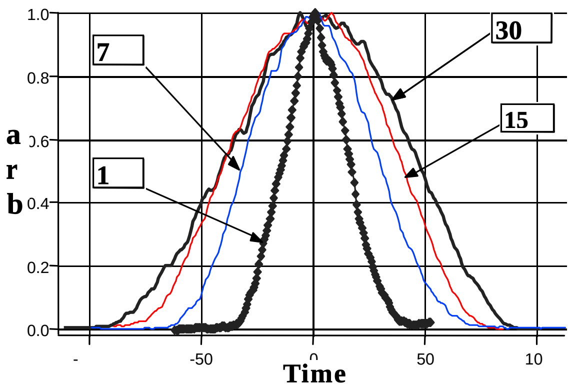

Fig.6: single bunch profiles at 1, 7, 15 and 30mA.

The charge/bunch being equal for both fillings, a direct comparison of the acquired data has been possible. The data show a very good agreement, except at higher currents where a small difference of 2 to 3ps is visible. This small increase in the four-bunch mode is not at present understood. It is not thought to be due to bunch oscillations since other streak camera images, as well as other measurements, indicated an absence of bunch motion.

6.3.1 Stability investigations

For these measurements the SC has been used in Syncroscan mode, with the fast axis set to 441ps and the slow axis ranging from 1µs to 35ms. For FEL operation the SC confirmed the instability free settings, see fig.7.

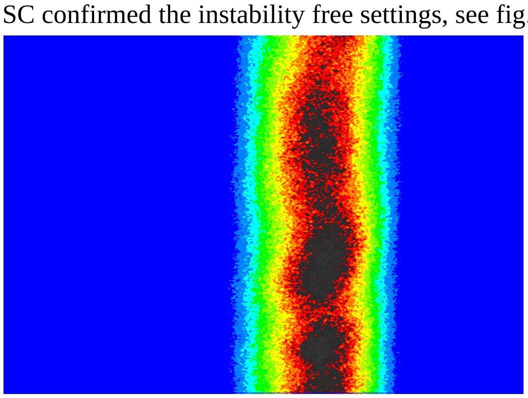

Fig.7: synchroscan image of four-bunch mode beam. Scales: HOR.=441ps, VERT.=34µs.

7 CONCLUSIONS

The Streak Camera system recently installed at ELETTRA has been presented in this paper. A description of the system has been given together with the first measurements. Future work will provide a Local Control Panel which will enable non-expert Users to safely perform measurements with this powerful diagnostic tool.

8 ACKNOWLEDGEMENTS

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