BEAM DIAGNOSTICS AT IR WAVELENGTHS AT NSRL

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Abstract

Real time diagnostics is a fundamental tool for accelerator physics, particularly important to improve performances of synchrotron radiation sources, colliders and a challenging key issue for 4^{th} generation sources and FEL's. Here we report the first measurements in the time and frequency domains of longitudinal bunch lengths performed at the Hefei Light Source, the dedicated synchrotron radiation facility of the National Synchrotron Radiation Laboratory (NSRL). A fast uncooled HgCdTe photodiode optimized in the mid-IR range has been used to record at the IR port the length of individual bunches. These detectors are compact and low cost devices suitable to characterize the bunch length for a bunch-by-bunch longitudinal diagnostics and useful to investigate longitudinal oscillations. The IR signal has been also used to measure the synchrotron oscillation frequency, its harmonics in the multi-bunch mode and bunch lengths in the multi-bunch mode vs. the beam current. For the first time, simultaneously to IR acquisition, data have been collected at NIR/IR wavelengths using a fast photodiode at the diagnostic beamline of the HLS. A comparison between the data sets will be presented and discussed.

INTRODUCTION

Beam diagnostics are fundamental tools for storage rings and particle accelerators. Diagnostic techniques are important to characterize and improve performances of existing synchrotron radiation sources and colliders and certainly represent one of the most challenging issues of all 4^{th} generation sources such as x-ray FEL's [1]. At the Laboratori Nazionali di Frascati (LNF) of the INFN in the framework of the 3+L experiments funded by the V^{th} Committee we recently set up at DAΦNE a diagnostics experiment to monitor the real time behaviour of the positron bunches [2,3]. This experiment collects the synchrotron radiation emitted from a bending magnet to store bunch-by-bunch profiles and lengths of the accumulated positrons. Compact and fast IR devices with a sub-ns response time are used to measure the positron emission. Because the bunch length at DAΦNE is at the limit of the time response of these devices and in order to compare our data with those collected with another radiation source using the same technique, we set up a similar experiment to measure the emission of electron bunches at the available IR port of the Hefei Light Source (HLS), the dedicated synchrotron radiation facility of the National Synchrotron Radiation Laboratory (NSRL). Both bunch separation and length at HLS are slightly larger than at DAΦNE, i.e. the bunch separations are 5 ns and 2.7 ns, respectively, while the corresponding FWHM bunch lengths are ~500-700 ps and 150-300 ps. Differences between bunch lengths may help to better understand both response times and data collected in the framework of the 3+L experiment. With this diagnostics technique at IR wavelengths, both profiles and longitudinal lengths of single bunches, important parameters for both machine physicists and synchrotron radiation users can be monitored in real time during standard experimental runs.

EXPERIMENTAL SET-UP

At Hefei a compact IR photo-detector has been installed inside the high vacuum chamber that hosts the final optical element of the IR beamline. The optical system composed by reflecting mirrors collects and focuses the IR beam to the entrance of a BRUKER v60 interferometer. In the experimental set-up after the optical system, a small elliptical mirror deflected and focused the IR beam on the device placed before the entrance of the interferometer. Fig. 1 shows a photo showing the elliptical mirror focusing the IR beam on the active area of the photodiode.

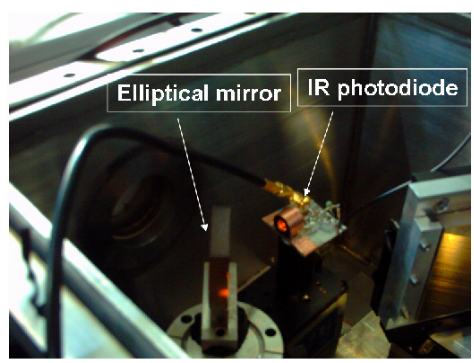

Figure 1: The photodiode and the elliptical mirror inside the HV chamber at the end of the IR beamline.

IR detectors are based on HgCdTe multilayer hetero-structures grown by MOCVD technology on oriented GaAs (211) and (111) substrates. These photo-detectors are optimized to work in the mid-IR at 10.6 µm. Presently the best response time of these detectors are of the order of 100 ps or lower when cooled at 205 K with a 3-stage

Peltier cooler [4]. Because of the low energy of the HLS ring, accelerator components, beamlines and experimental setups are hosted in the same hall. As a consequence to shield the electro magnetic signal generated by the radio frequency cavity the IR detector was installed inside a metallic box. Actually, the RF klystron is very close to the IR beamline and contributes significantly to the noise of the detector. While the peak-to-peak voltage of the RF signal detected by the IR device was about 150-300 mV in the current range 100-300 mA the same detector inside the metallic box measured a peak-to-peak signal of about 80-100 mV. IR signals were amplified by a fast commercial voltage amplifier with 0.01-2500 MHz bandwidth and ~40 dB gain. Data were stored with a digital phosphor 7 GHz scope (model Tektronics 7704B) and single-shot sample rates up to 20 GS/s. An USB-GPIB adapter was used to connect the scope to a PC and data were stored with a LabVIEW software.

EXPERIMENTAL DATA

To monitor the longitudinal bunch lengths we performed measurements in the time domain with IR photodiodes at room temperature. At HLS the RF frequency is 204.016 MHz and the revolution frequency is 4.534 MHz. The full-fill pattern of the machine is 45 bunches with a total beam current in the range 100-300 mA with a bunch separation of 4.9 ns in the full fill pattern. The layout of the bunch structure of the 45 e^- bunches is reported in Fig. 2 as collected with this photodiode.

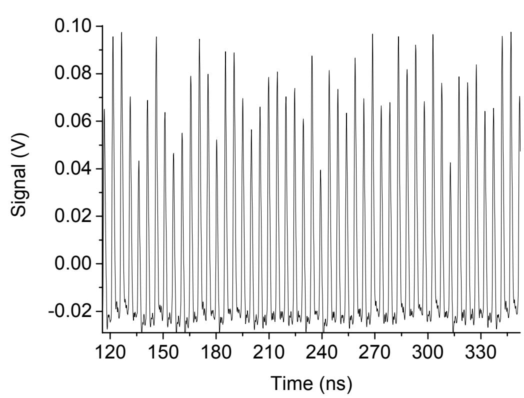

Figure 2: IR signal of the 45 e^- bunches of the HLS ring.

In the full-fill pattern mode the IR photodiode is able to fully resolve the time structure of the electron bunches as well as the pattern of each individual bunch as showed in Fig. 3. Data in Fig. 3 refer to a beam current of 118 mA and the bunch length calculated by the Gaussian fit is σ ~ 262 ps, a reasonable value for this beam current.

In order to compare the measurements at IR wavelengths with a different method, data of the same bunches and at the same time have been collected using the experimental set-up available at HLS. Indeed, at Hefei, a diagnostics beamline working at visible and NIR/IR wavelengths, dedicated to monitor the longitudinal dimensions of the electron beam using a fast InGaAs photodiode optimized in the 750-1700 nm range, is already operational as well as a streak camera. [5] Using our set-up, for the first time at HLS, data at NIR/IR wavelengths using the InGaAs photodiode of the diagnostic beamline and IR data using our HgCdTe photodiode were simultaneously collected.

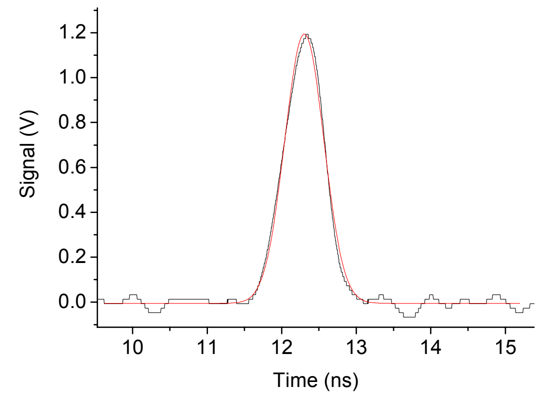

Figure 3: Emission of one electron bunch (black line) and its Gaussian fit (red line).

Data were acquired with two scopes (models Tektronics TDS7704B and a TDS6154C) using a LabVIEW software based on the TekVISA package supported by both scopes and stored in a common PC. Scopes were remotely controlled over a LAN using the VXI-11 protocol and a 10Base-T Ethernet connection together with the virtual GPIB software running on the two scopes. In particular, in Fig. 4 we compared the signal of four consecutive bunches measured with the IR (red line) and the InGaAs photodiodes (black line). A qualitatively good agreement between the profiles yielded by the two photon-detectors working at different wavelengths is shown in Fig. 4.

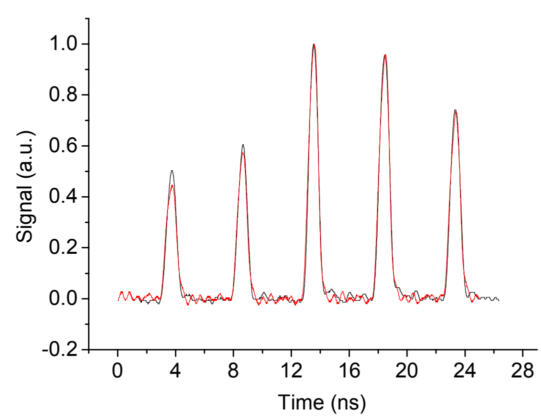

Figure 4: Data of 4 consecutive bunches collected at IR (red line) and at NIR/IR (black line) wavelengths with the two photodiodes.

In order to better characterize bunch lengths, we performed bunch length measurements of the electron beam vs. the beam current at the IR port and compared data with those of the diagnostics already available at HLS. Actually, during runs at HLS, after bunch re-filling we collected the signal of each bunch with both the IR and the InGaAs photodiodes monitoring the length vs. beam current behaviour. The FWHM of the bunch as a function of the beam current is reported in Fig.5 where the red line refers to data of the IR photodiode while the black one refers to data collected by the InGaAs detector.

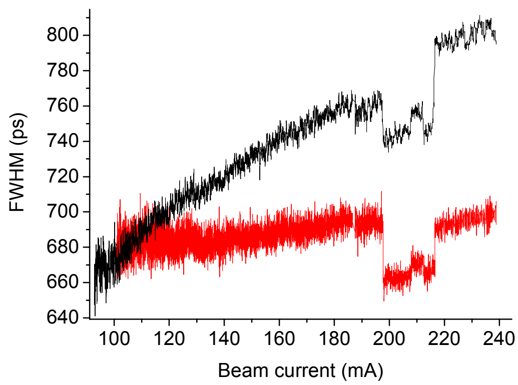

Figure 5: Comparison of bunch length vs. beam current measured at IR (red) and NIR/IR (black) wavelengths.

Although the FWHM of the bunch length, as measured by two detectors, shows a similar behaviour and the same bunch longitudinal dynamics (e.g., the sudden change observed during the run), the visible photodiode indicates a total variation of about 140 ps between the min. and the max. values of the beam current while for a beam current > 110 mA the FWHM bunch length measured by the IR photodiode is smaller than the corresponding one from the visible photodiode and exhibits a slower increase. However, during the run shown in Fig. 5, in the range 190-220 mA both detectors monitor the same variations of the beam emission, although data do not allow understanding the origin of the observed phenomenon. Finally it is important to underline that the S/N ratio of the data collected with our IR photodiode allowed acquisition with the scope in the single shot mode while due to the lower S/N ratio, data with the InGaAs photodiode is the result of the average of 15 individual acquisitions.

At Hefei we performed also IR measurements in frequency domain. Data were useful to investigate the longitudinal oscillations of the e$^-$ beam. In particular, the signal allowed measuring the synchrotron oscillation frequency and its harmonics in the multi-bunch mode. In Fig. 6 we show the spectral signal measured with a real-time Spectrum Analyzer (model Tektronics RSA6114A) and relative to the IR signal. The synchrotron frequency oscillation is about 35 kHz, a value comparable with that obtained by the HLS diagnostics group with dedicated diagnostics techniques. [5]

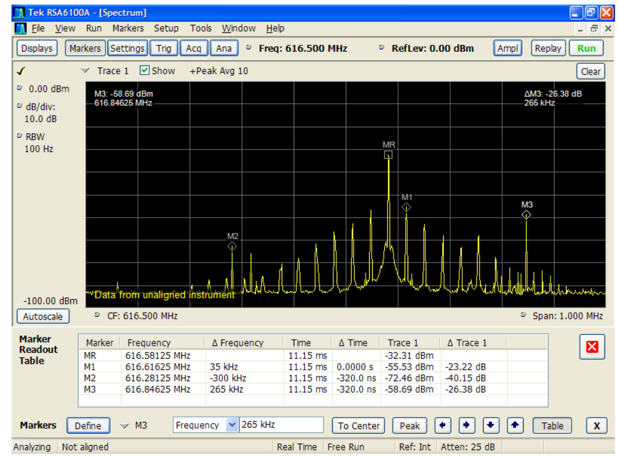

Figure 6: The frequency domain measurement of the beam longitudinal oscillations as measured with the IR detector.

CONCLUSIONS

For the first time a characterization of the bunch lengths of the e$^-$ beam has been carried out at the IR beamline station of the HLS ring using a fast IR photodiode. IR data have been collected and compared with those of a visible photodiode installed at the visible diagnostics station at HLS. Although preliminary, the results achieved show that diagnostics at IR wavelengths is possible in the sub-ns time domain using IR uncooled photodiodes which can be successfully used in different accelerators. Better results could be obtained using cooled and faster IR photodiodes coupled to a dedicated fast electronics pushing the present time resolution limits. Work is in progress to analyze data and to design an improved setup at HLS for simultaneous IR and visible data acquisitions.

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