STATUS OF ELECTRON BUNCH LENGTH MEASUREMENTS WITH ELECTRO-OPTICAL METHODS AT THE SLS LINAC

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The measurement of electron bunch-length with sub-ps time resolution is mandatory for future X-ray free electron lasers. The correlation of coherent far microwave transition radiation, emitted by short relativistic electron bunches, and laser radiation in electro-optical crystals represents one of the most promising approaches. Therefore, two bunch-length monitors, applying electro-optical techniques have been set-up at the SLS Linac. This report presents the experimental set-ups and summarizes the status of the measurements, which have been performed in close collaboration between the PSI diagnostics group and physicists from DESY (Deutsches Elektronen Synchrotron, Hamburg, Germany.

INTRODUCTION

Future X-ray free electron lasers (XFEL) are based on the so called SASE (self amplifying spontaneous emission) process, requiring extremely high electron peak currents of some kA, which are usually achieved by electron bunch compression resulting in bunch lengths as short as some tens of femtoseconds. The measurement of such short bunches and the control of the bunching process is mandatory for stable operation of XFELs. The correlation of coherent microwave radiation emitted by short relativistic electron bunches with laser radiation in electro-optical (EO) crystals represents one of the most promising approaches for measuring electron bunch lengths with sub-ps time resolution. In this context two complementing EO bunch length monitors applying a sampling and an auto-correlation technique are set-up at the SLS linac, where coherent transition radiation (CTR) is emitted at the ALIDI-SM-5 monitor. While the sampling of the ps long CTR pulse from the SLS linac with the 15 fs long Ti:Sa laser pulse may provide good signal to noise (S/N) ratios, the requirements for synchronization of laser and electron pulses are extremely high. The auto-correlation technique on the other hand has much more relaxed timing and synchronization requirements and promises single shot capability. However, the expected moderate S/N ratio and the quite complex data analysis represent some of the drawbacks of this method. A comparison of the measurements at the SLS linac should provide information about the complexity, applicability during standard accelerator operation as well as time resolution of both techniques.

EO-AUTO-CORRELATION

In the course of a PhD thesis, a bunch length monitor based on the EO effect in a ZnTe crystal induced by CTR is presently under development at PSI. In this experiment, the vertical polarization component of the CTR is auto-correlated in an EO crystal producing a spatial interference pattern. The induced electrical field strength rotates the polarization of an actively mode locked Nd:YAG laser (< 400 ps pulse length, > 1mJ pulse energy @ 1064 nm wavelength and up to 10 Hz repetition rate). The spatially modulated laser power, which is transmitted through the analyzing polarizer, is focused on a linear array detector, providing (single shot) information about the spectral content of the CTR pulse. Further data analysis allows reconstruction of the longitudinal charge distribution of the electron bunches.

EO-SAMPLING

The method of EO sampling will be applied for bunch length measurements at TTF VUV FEL at DESY, Hamburg. In this technique the 15 fs short Ti:Sa laser pulses are superimposed on the CTR emitted by the electron bunches in an EO crystal. In case of temporal coincidence of the laser and the CTR pulses, the polarization of the laser pulse is rotated and the laser power, which is transmitted through an analyzing polarizer, is detected by a balanced receiver [1]. While the data analysis is straight forward, much effort has to be put into the synchronization between the Ti:Sa laser pulses and the electron bunches to achieve the desired (sub-ps) time resolution.

SET-UP OF EO-EXPERIMENTS AT THE SLS LINAC

Both, the Ti:Sa and Nd:YAG lasers have been set-up on an optical table in the SLS technical gallery, close to the linac bunker. The laser pulses are transported through an 18 m long optical transfer line onto a second optical table close to the ALIDI-SM-5 TR-monitor behind the linac. The long wavelengths, coherent part of the TR is coupled out of the UHV system through a crystalline quartz window and focused onto the EO crystal using two off axis parabolic mirrors. A pellicle beam splitter, which is mounted at 45° angle in the optical path of the CTR, reflects the laser pulses onto the crystal, where coincidence can be achieved in case of proper synchronization. The optical part of the TR (OTR), which has a much smaller emission cone than the long wavelength CTR, is passed through a central hole of the first parabolic mirror and focused onto a photomultiplier (PM) or a fast photo-diode (PD). A coincidence signal between the OTR and the laser pulses on the PM resp. PD provides a coarse synchronisation between laser and TR pulses on a sub-ns time scale. Once, such a coarse timing has been achieved, stepwise delays (ps steps) of the laser pulses in respect to the electron bunches will finally produce the coincidence in the EO crystal. Optionally, the transmitted laser power can then be coupled into optical fibres and detected by a balanced receiver in the SLS technical gallery or it can be transmitted to a diode detector on the optical table in the linac bunker.

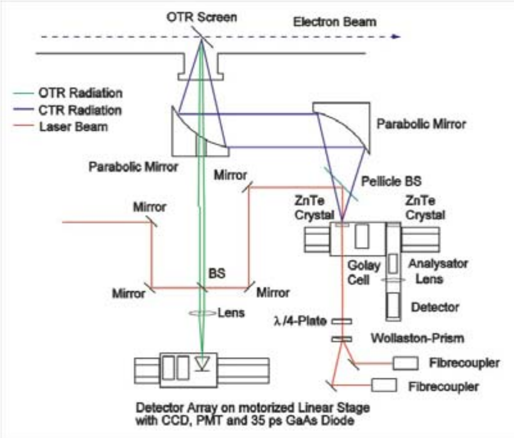

Fig. 1: Schematic set-up of the combined EO measurements at the ALIDI-SM-5 monitor behind the 100 MeV SLS pre-injector linac.

While EO-sampling is already possible with the set-up as shown in Fig. 1, the present configuration is only a first step towards the final EO-auto-correlation measurements emphasising on Nd:YAG laser as well as timing and control system issues. The more complex optical path in case of the EO auto-correlation method requires more extensive theoretical and experimental characterization of the CTR, which has also been performed during 2003 at the SLS linac.

FIRST RESULTS

The CTR emission process could be experimentally characterized and the results match the theoretical expectations [2, 3].

The required smooth temporal profile of $\sigma = 400$ ps with timing jitter of < 0.5 ns rms of the Nd:YAG laser system was measured with a streak camera at the SLS diagnostics beamline.

CTR electrical field strengths exceeding 3 kV/cm have been measured in the focal plane with the Golay cell detector. Field strengths of 1 kV/cm should be enough for sufficient S/N ratios in the EOA experiment.

A so called “top-up and EO” operation mode of the SLS pre-injector linac has been introduced, which allows simultaneous EO measurements and top-up operation of the SLS storage ring.

The synchronization of the electron bunches from the SLS pre-injector linac with the Ti:Sa laser pulses was achieved by phase locking (PLL) the 81 MHz repetition rate of the laser to the 500 MHz SLS RF frequency at a mixing frequency of 3.5 GHz corresponding to a frequency ratio of 43/7. A modification of the electron gun trigger system had to be made to make sure, that electron bunches are only injected for every 7th laser pulse. Phase shifting of the mixing signal to a precision of 0.1° by using a vector modulator is required for successful accomplishment of the EO-sampling technique. In this respect, the use of stabilized low emission power supplies in the electronics circuits of the synchronization scheme has been one of the most crucial issues to minimize jitter of the synchronization. The loop is finally closed, when the down-converted signal is applied to a piezo, which regulates the repetition rate of the Ti:Sa laser by adjusting a mirror inside the laser. Comparison of the error signals in the closed loop state to those in the open loop state provides information about the accuracy of the PLL. The open loop signal for a 45° phase shift at the down mixing frequency of 3.5 GHz was measured to be 450 mV rms, which is equivalent to a resolution of 1 mV per 80 fs. Preliminary measurements indicate that the average jitter of the closed loop signal is in the order of 1.2 mV rms, corresponding to a synchronization stability of 96 fs between laser and electron pulses.

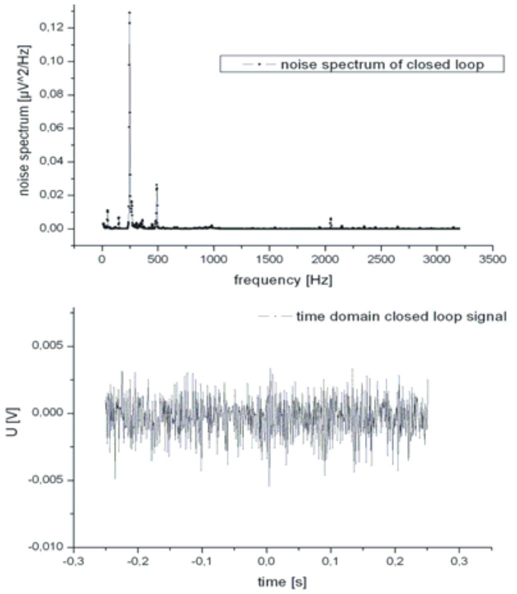

Fig. 2: Noise spectrum (top) and time domain (bottom) of closed loop synchronization signals.

OUTLOOK

It is planned to perform several further measurement campaigns until summer of 2004 predominantly in the SLS shut-down periods, when the pre-injector linac can be operated independently. The Nd:YAG laser will be upgraded (in February 2004) to slightly shorter pulse lengths (150 – 300 ps) and smoother and more reproducible temporal profiles to reduce intensity fluctuations, when acquiring auto-correlation signals. The final EO auto-correlation set-up will be installed within the next quarter of the year. First measurement results are expected in summer 2004.

REFERENCES

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