

ELECTRO OPTIC BUNCH LENGTH MEASUREMENTS AT THE VUV-FEL AT DESY

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Abstract

For the operation of a SASE FEL, the longitudinal bunch profile is one of the most critical parameters. At the superconducting linac of the VUV-FEL at DESY, an electro optical sampling (EOS) experiment was installed to probe the time structure of the electric field of the bunches to better than 100 fs rms. The field induced birefringence of a ZnTe crystal is detected by a femtosecond laser pulse (TiSa) and the time structure is measured by scanning the relative timing of the electron bunch and the TiSa pulse. A synchronization stability of better than 70 fs between laser and accelerator RF has been achieved. First results on the synchronization and the bunch profile measurements are presented.

INTRODUCTION

Bunch length measurements in the 100 femtosecond regime are of high interest for VUV and X ray free electron lasers. The electro-optical sampling (EOS) and other electro-optical techniques provide the possibility to measure the longitudinal charge distribution with very high resolution, determined by the dispersion of the electric field pulse in the nonlinear optical crystal, the relative time jitter between electron bunch and laser pulse and the width of the optical laser pulse. At DESY, a 25 fs titanium-sapphire (Ti:Sa) laser is used to sample the birefringence which is induced in a nonlinear electro-optical crystal by the co-moving electric field of a relativistic electron bunch. In the EO crystal, the initial linear polarization of the laser pulse is converted into a slightly elliptical polarization which is then converted into an intensity modulation. By shifting the timing of the laser pulse relative to the bunch in subpicosecond steps the time profile is obtained by sampling over many bunches. Previous accelerator-related EOS experiments have been carried out at the infrared free electron laser FELIX [1], Fermilab, the TESLA Test Facility TTF [2], SLAC and SLS [3, 4].

EXPERIMENTAL SETUP

The Ti:Sa laser has a pulse width of 25 fs, a central wavelength of 800 nm and a bandwidth of 50 nm. It is mounted on a vibration-damped optical table outside the tunnel. The laser beam is guided into the linac tunnel by a 20 m long optical transfer line equipped with four mirrors and two lenses ($f = 4$ m) which image the Ti:Sa laser onto a 300 μm thick ZnTe crystal in the linac beampipe. The

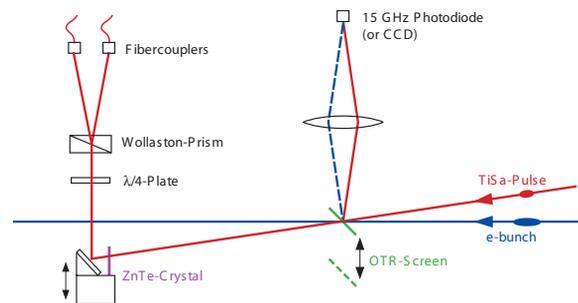


Figure 1: Schematic of the EOS setup. An OTR screen can be moved into the e-beam to adjust the relative timing between the laser pulses and the electron bunches with ≈ 200 ps precision.

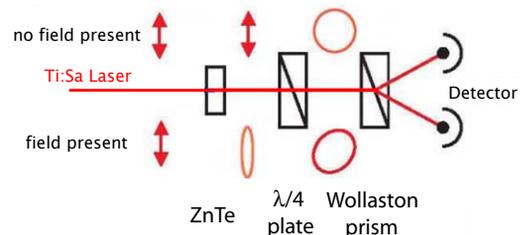


Figure 2: Simplified view of the signal detection using a quarter-wave plate, Wollaston prism and a balanced diode detector. The laser and the field of the bunch are polarized horizontally, parallel to the $(-1,1,0)$ axis of the ZnTe crystal.

dispersion in the lenses stretches the laser pulses to about 120 fs FWHM. Since the laser pulse length is presently not limiting the resolution, the pulse lengthening was not compensated. The beam transfer line has proven very stable, neither short-term nor long-term motions of the laser spot position on the ZnTe crystal were observed.

Inside the linac tunnel an optical table is installed which holds the beampipe and the detector optics (see Fig. 1). A spherical mirror ($f = 1$ m) focuses the laser on the ZnTe crystal. The laser beam is injected into the beampipe at an angle of 6° with respect to the e-beam. Thereby we avoid a mirror upstream of the crystal which might produce wakefields. Behind the crystal a mirror reflects the laser beam to the detector optics outside the vacuum chamber. Before starting an EOS measurement, an optical transition radiation (OTR) screen can be moved into the e-beam to adjust the relative timing between the laser pulses and the electron bunches with ≈ 200 ps precision.

A simplified view of the signal detection scheme is

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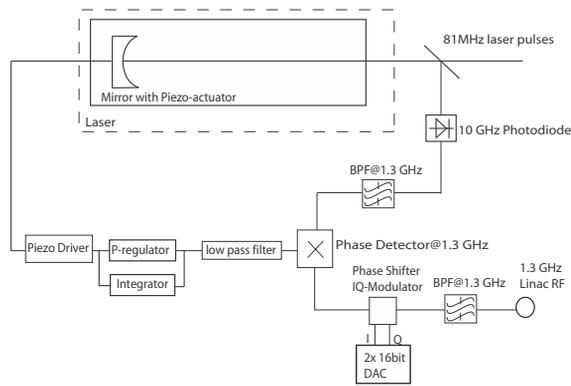


Figure 3: Schematics of the setup used to synchronize the laser to the RF. The laser repetition frequency is 81 MHz. The 16th harmonic of the laser frequency is phase-locked to the 1.3 GHz radio frequency of the linac.

shown in figure 2. ZnTe is optically isotropic at vanishing field but acquires a birefringence in the presence of a strong electric field. The crystal is cut in the (110) plane with the the crystallographic (-1,1,0) axis oriented horizontally. Both the field of the bunch and the Ti:Sa pulse are polarized horizontally. The induced birefringence can be described by a refractive index ellipse whose large axis is rotated by 45° with respect to the horizontal axis. The laser polarization components along the two main axes of the index ellipse acquire a phase shift difference when passing the crystal of $\Gamma \propto r_{41} E_e$ where r_{41} is the electro optical coefficient of ZnTe and E_e the electric field of the bunch. Behind the ZnTe crystal the laser pulse will then be elliptically polarized. The most sensitive method to measure this ellipticity is to pass the beam through a quarter wave plate, transforming the slight elliptic polarization into a slightly perturbed circular polarization, and then through a Wollaston prism, which serves for a spatial separation of the two orthogonal polarization components. These are then coupled into optical multimode fibers and guided to a balanced diode detector located outside the linac tunnel. In the case of a coincidence between the electron bunch and the laser pulse the balanced detector signal is proportional to $\sin(\Gamma)$ and thereby roughly proportional to the electric field of the bunch. Without temporal overlap of the two pulses the balanced detector signal will vanish.

To scan the longitudinal bunch profile, a vector modulator is used to vary the relative delay between the 1.3 GHz reference signal and the laser pulse in 50 - 100 fs steps. The EOS technique samples over many successive bunches and therefore depends critically on a low jitter in the arrival time of the bunches at the ZnTe crystal. Moreover, the synchronization between the femtosecond laser and the 1.3 GHz master oscillator of the linac RF must be very precise. The synchronization scheme is shown in figure 3. The measured phase noise is shown in figure 4. From these data we derive a time jitter of less than 70 fs. A more comprehensive description of the synchronization scheme can be

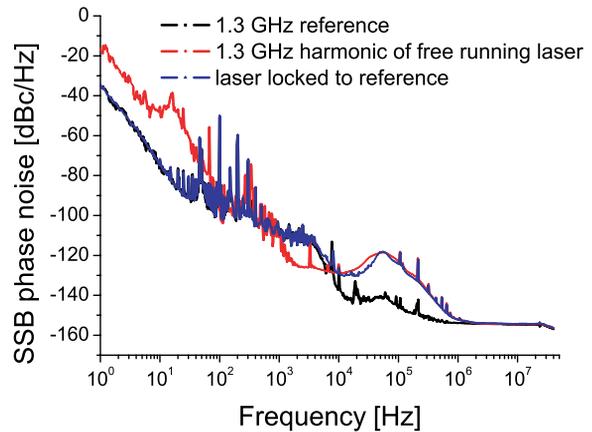


Figure 4: Phase noise of the 1.3 GHz reference signal, the free running laser and the laser locked to the reference.

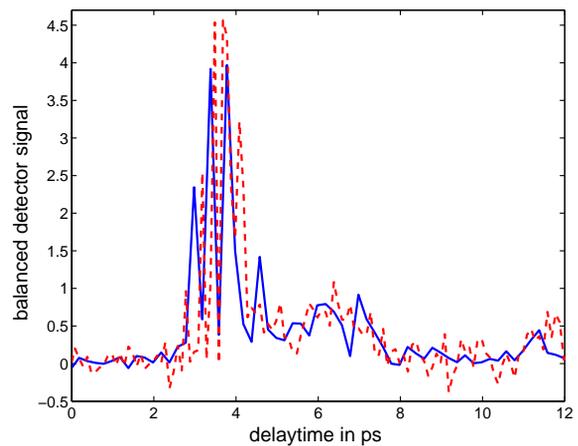


Figure 5: Two EOS measurements of short bunches, the second (dashed) measured approx. two minutes after the first (solid) (bunch charge 1.2 nC).

found in [5].

EOS MEASUREMENTS

The first EOS data taken at the linac of the VUV-FEL show pulses with a rather spiky substructure and a width of the envelope of about 400 fs (rms) (Fig. 5). The expected bunch length of less than 100 fs (rms) cannot yet be resolved, presumably due to jitter in the bunch arrival time at the ZnTe crystal. One major source of this jitter are energy fluctuations of $\approx 0.03\%$ which translate into timing fluctuations of ≈ 250 fs (rms) in the magnetic chicane of the first bunch compressor. The overall width of the observed EOS peak is therefore dominated by the time jitter while the position of the spikes within the envelope fluctuates statistically. Work is in progress to increase the stability of the linac.

Recent single-bunch measurements with a transverse deflecting cavity have revealed bunch lengths of 20 to 100 fs (rms) [6].

CONCLUSION

The first clear EO signals with an internal ZnTe crystal have been established. A precise bunch profile determination is presently not possible due to arrival time jitter of the electron bunches at the EO crystal. To eliminate the jitter problem the EO setup will soon be modified to allow single-shot measurements with stretched laser pulses using the spectral decoding technique [7].

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