RECENT DEVELOPMENTS AT THE DELTA THz BEAMLINE*

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Abstract

During 2011, a dedicated THz beamline has been constructed and commissioned at DELTA, a 1.5-GeV synchrotron light source operated by the TU Dortmund University. This beamline enables extracting and detecting coherent THz pulses caused by a laser-induced density modulation of the electron bunches. Apart from using THz radiation as a diagnostics tool, ongoing experiments aim at characterizing the radiation as well as investigating the evolution of the density modulation over subsequent revolutions following the initial laser-electron interaction in an undulator.

INTRODUCTION

The 1.5-GeV synchrotron light source DELTA (Fig. 1) operated by the TU Dortmund University provides a beam current of up to 130 mA in multibunch mode or typically 15 mA in single-bunch mode at a revolution frequency of 2.6 MHz.

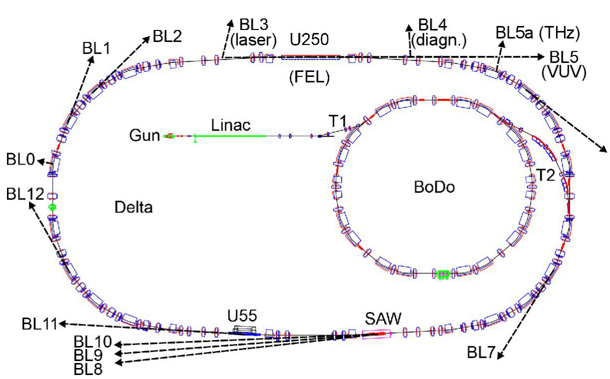

Figure 1: Sketch of the DELTA facility including the laser beamline (BL3), diagnostics beamline (BL4), VUV beamline (BL5), and THz beamline (BL5a).

The New Short Pulse Facility

A source for ultrashort VUV and THz pulses based on the Coherent Harmonic Generation (CHG) principle has been commissioned during 2011 [1, 2, 3]. Pulses with a duration of 40 fs from a Ti:sapphire laser (BL3, Fig. 1) copropagate with the electron bunches in the modulator (first part of the undulator U250), which leads to an energy modulation in a short slice of the bunches. A dispersive section (center part of the U250) transforms the energy modulation into a sequence of microbunches, which emit coherent radiation at harmonics of the original laser wavelength in the radiator (last part of the U250). The CHG radiation is extracted by the diagnostics beamline (BL4) or the VUV beamline (BL5). Due to path length differences in the following dipole magnets, a sub-picosecond dip in the longitudinal electron density is formed. Based on previous experience at BESSY [4], a THz beamline (BL5a) has been constructed in order to extract and detect coherent THz pulses caused by this density modulation [5].

The THz Beamline

After a total longitudinal dispersion of $R_{56} = 5.75$ mm downstream of the U250 section, a modified dipole chamber allows the extraction of a circular THz beam profile with an opening angle of 33 mrad.

The THz radiation is first reflected by a water-cooled and gold-coated plane copper mirror and then guided and focused by six toroidal aluminium mirrors (M1 - M6). Each pair of focusing mirrors forms a Gaussian telescope (sum of focal lengths equals the distance between the mirrors), providing wavelength-independent focusing. Near the focal point between M1 and M2, a z-cut quartz window separates the beamline vacuum from the ultrahigh vacuum inside the storage ring. The beamline tubing is coated with aluminium foam to suppress pulse lengthening due to multiple reflections.

The detector is a liquid-helium-cooled hot-electron bolometer comprising an indium antimonide detector chip with a response time of 0.3 μs and a spectral responsivity reaching from 60 to 500 GHz (2 to 15 cm^{-1}). The preamplifier provides an intensity-proportional voltage and a bandwidth of 1 MHz. The signal is recorded by a 1-GHz oscilloscope and can be fed into the EPICS control system.

EXPERIMENTAL RESULTS

Longitudinal Electron Bunch Profiles

The coherent THz radiation intensity is proportional to the number of laser-affected electrons squared. As the laser pulses are short in comparison to the bunch length of about 100 ps, the THz signal can be used to record longitudinal bunch profiles by shifting the timing between storage ring RF and laser trigger. Measurements performed with a longitudinal bunch-by-bunch feedback system [6] show no significant jitter of the bunch timing, indicating that such profiles provide the real bunch length.

During standard user operation with multiple bunches, a

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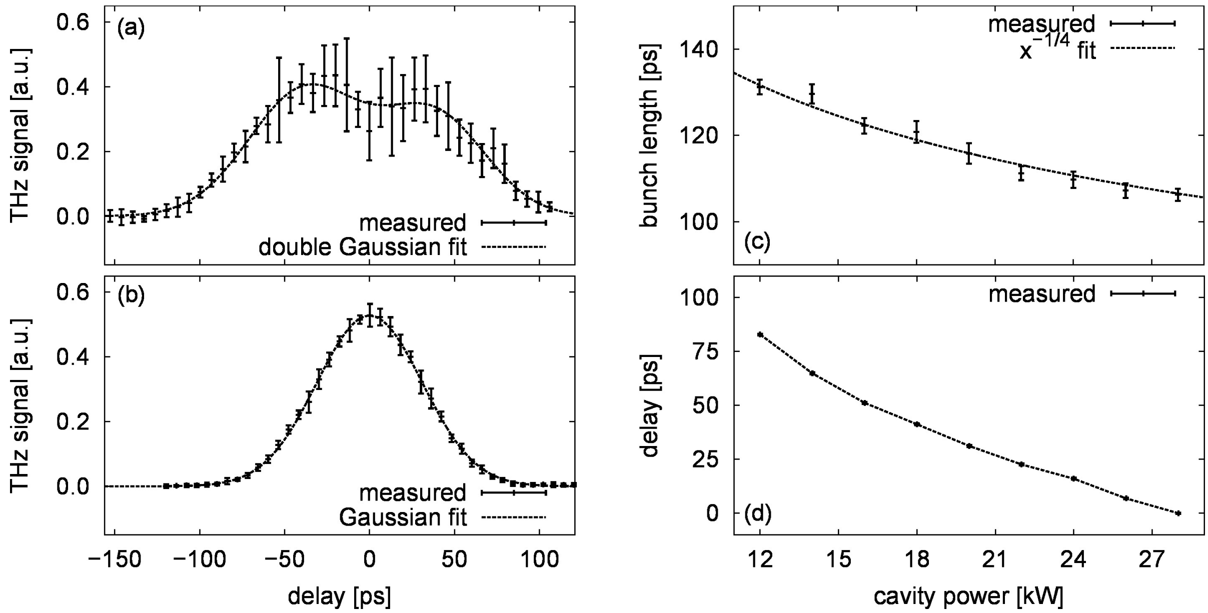

Figure 2: THz signal versus delay between the laser pulses and the electron bunch (a) with and (b) without an RF phase modulation. The square root of the THz signal is directly proportional to the longitudinal electron density. The dependence of the bunch length (c) and the synchronous phase (d), here in time units, on the RF power is studied using such profile measurements.

phase modulation is applied to the RF generator in order to reduce multibunch instabilities and to increase the beam lifetime. This leads to the time-averaged bunch profile shown in Fig. 2 (a) with a total half-width of (221.9 ± 19.8) ps. During CHG operation (single bunch), the RF phase modulation is switched off to maximize the peak current, resulting in a Gaussian beam profile (b) with a total bunch length of (103.6 ± 0.7) ps (FWHM).

Using bunch parameters gained from such longitudinal profiles, the dependence of the bunch length on the RF power P_{RF} was studied. In accordance with expectations, a decrease $\propto 1/\sqrt[4]{P_{\mathrm{RF}}}$ was observed (Fig. 2 c). As the electrons' energy loss per revolution stays constant, the synchronous phase angle changes under variation of the RF power (d).

Similar measurements at different single-bunch currents up to 15 mA and constant RF power (standard setting of 25 kW) have revealed that the bunch length stays slightly above 100 ps (FWHM); bunch lengthening due to potential-well distortion or turbulent bunch lengthening does not occur. This is consistent with the absence of a microbunching instability leading to spontaneous coherent THz bursts, which has been observed elsewhere [7].

Transverse Electron Bunch Profiles

By transversely displacing the laser pulses using a mirror in BL3, the transverse electron distribution can be studied. As laser pulses and electron bunches both have a width of several hundred micrometers, the THz signal corresponds to the squared convolution of both profiles.

Such a measurement is shown in Fig. 3, leading to a convolution width of (899 ± 13) μm (FWHM). The deviation

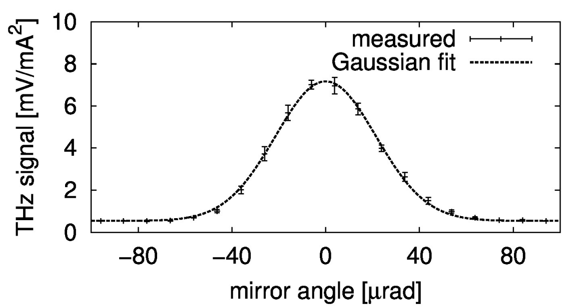

Figure 3: THz signal versus horizontal angle of a mirror in the laser beamline (BL3). The square root of the THz signal is proportional to the convolution of the horizontal electron bunch and laser pulse profiles.

from a calculated width of $2\sqrt{2\ln 2}\sqrt{\epsilon\beta + w_L^2} = 1015\,\mu$m (FWHM) may be explained by inaccuracies in mirror calibration and measurement of the laser waist w_L as well as uncertainties in the knowledge of the beam emittance ϵ and the assumed beta function β at the modulator.

Other Measurements

Figure 4 shows the linear dependence of the square root of the THz signal on the bunch current, which is expected for a coherent radiation mechanism. The current was reduced using a horizontal scraper. For bunch currents well below 1 mA, the THz signal cannot be distinguished from the detector noise.

By rotating the laser polarization axis using a half-wave

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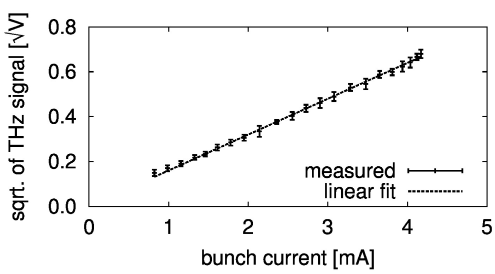

Figure 4: Square root of the THz signal versus single-bunch current.

plate, the electrical field component which causes the energy modulation in a planar undulator can be reduced. A linear dependence of the THz signal on the effective laser pulse energy has been observed (Fig. 5).

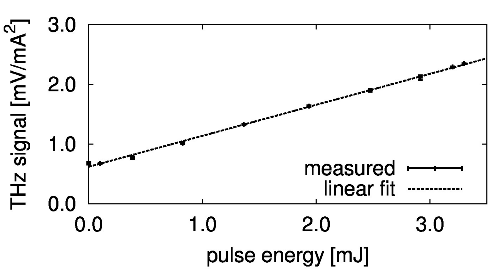

Figure 5: THz signal versus laser pulse energy.

When the laser pulse length was increased by changing the settings of the compressor following the laser amplifier, an increase of the THz signal was observed. This can be explained by an increase in the number of laser-affected electrons in combination with a shift of the THz spectrum (about 0.2 to 8 THz at 40 fs) to lower frequencies, at which the bolometer is more sensitive.

Bolometer Saturation Effects

Figure 6 (a) shows typical oscilloscope traces of laser-induced THz signals from the bolometer's preamplifier for different signal intensities. The shape is determined by the 1-MHz bandwidth of the preamplifier and the decreasing THz signal intensity from subsequent storage ring revolutions (384 ns revolution time) after the initial laser interaction.

At higher signal intensities (e.g. at higher beam currents or more laser power) this behavior changes (Fig. 6 b). The different traces have a constant rising edge steepness, while the maximum is shifted to later times. At even higher intensities, the signal is cut off by preamplifier saturation (not shown).

Due to the limited temporal resolution of the bolometer, more detailed conclusions on the signal evolution over subsequent storage ring revolutions have to be postponed.

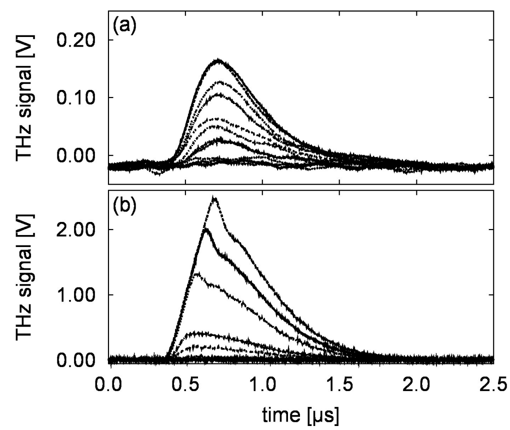

Figure 6: Oscilloscope traces of laser-induced THz signals with moderate amplitude (a). The different traces were recorded by reducing the spacial overlap between laser pulses and electron bunch. At THz signals with higher amplitude, a saturation effect in terms of a constant rising edge steepness is visible (b).

OUTLOOK

An FT-IR spectrometer for spectral characterization of the THz radiation and pulse shape investigations has been ordered and will be installed later in 2012. It is planned to establish a user facility for time-resolved FT-IR spectroscopy by sending a fraction of the seed laser pulse directly to the experiment (pump pulse) and probing the sample with a delayed THz pulse (pump-probe experiments).

More detailed theoretical and experimental analyses of the THz radiation mechanism are intended, especially regarding the evolution of the electron density modulation over several revolutions in the storage ring, using a faster hot-electron bolometer, e.g. [8].

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