TEMPORAL AND SPATIAL ALIGNMENT OF ELECTRON BUNCHES AND ULTRASHORT LASER PULSES FOR THE CHG EXPERIMENT AT DELTA*

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Abstract

The generation of ultrashort VUV pulses by Coherent Harmonic Generation (CHG) requires achieving and maintaining the longitudinal and transverse overlap of femtosecond laser pulses and electron bunches. We present the experimental setup and techniques applied at the DELTA storage ring. For the longitudinal analysis, both a fast photodiode and a streak camera are used. For transverse overlap, two CCD cameras acquire images of the laser and synchrotron light at different positions inside the undulator.

INTRODUCTION

In various fields of research and technology, short pulses with high photon energy are required to investigate phenomena occurring on the sub-picosecond timescale, while pulses of synchrotron radiation have a duration of several 10 ps. CHG is a method that enables the generation of ultrashort pulses in a storage ring. The operation principle of CHG is illustrated in Fig. 1. An ultrashort laser pulse with wavelength λ_L co-propagates with an electron bunch through the first undulator (modulator) with a period length λ_U. When the resonance condition

$$\lambda_L = \frac{\lambda_U}{2\gamma^2}\left(1 + \frac{K^2}{2}\right) \qquad (1)$$

is fulfilled, the electron energy is modulated periodically. K and γ in Eq. 1 refer to the deflection parameter of the modulator and the Lorentz factor of the electrons, respectively.
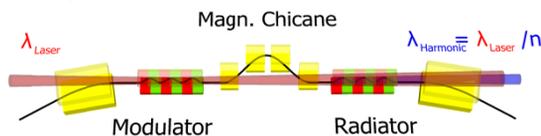

Figure 1: Scheme of Coherent Harmonic Generation.

As the electron bunch travels through a magnetic chicane, the energy modulation is converted into a density modulation, also called microbunching. The created microbunches pass through the second undulator (radiator) and radiate coherently at harmonics of the initial laser wavelength [1, 2].

A CHG facility is currently commissioned at DELTA [3], a synchrotron light source with a 1.5-GeV storage ring of 115.2 m circumference, operated by the TU Dortmund University in Germany. The main parameters of the experiment at DELTA are given in Tab. 1:

Table 1: Commissioning Parameters

Electron Bunch	
Electron energy	1.5 GeV
Bunch current	2-10 mA
Natural bunch length	85 ps (FWHM)
Modulator / Radiator	
Period length	250 mm
Number of periods	19
K value	10.2 / 7.0
Chicane R_{56}	15 µm
Ti:Sapphire Laser	
Wavelength	795 nm
Pulse length	40 fs (FWHM)
Max. pulse energy	8 mJ
Repetition rate	1 kHz
Quality factor M^2	1.5
Waist size (2σ)	750 µm × 550 µm

CHG SETUP

The layout of the CHG facility, which is located at the northern straight section of DELTA, is shown in Fig. 2. A Ti:Sapphire laser system is used as the seeding light source. The *p*-polarized laser beam is focused by a three-lens telescope to form a beam waist at the center of the modulator. Two plane dielectric mirrors (M$_1$ and M$_2$) equipped with stepper motors under EPICS control are used to guide the laser light through the laser beamline (BL3) into the optical klystron U250. Approximately five meters downstream of the undulator, the radiation is sent to the diagnostics hutch (BL4) by using a water-cooled copper mirror (M$_3$). Further downstream, the path-length differences of the off-energy electrons create a gap in the electron bunch, resulting in coherent THz radiation which is extracted at BL6 [4]. CHG radiation can be transmitted by BL5 to the experimental station operated by the Forschungszentrum Jülich. A fraction of the laser light (~10%) will be sent by an evacuated beamline (under construction) to the experimental station in order to perform time-resolved pump-probe measurements.

ALIGNMENT

The first step of alignment is to guide the laser beam from the laser hutch into the U250, and for this purpose several methods are applied. Firstly, the laser light is centered on two aluminium screens S$_1$ and S$_2$ controlled
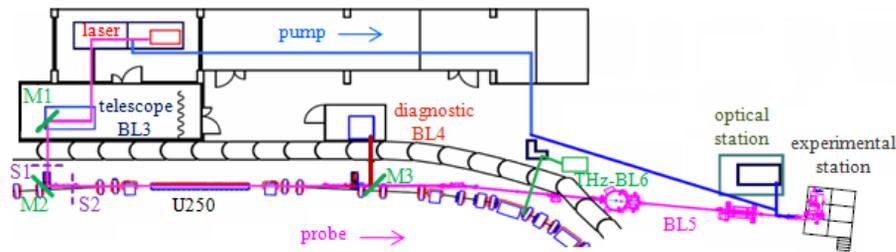
Figure 2: Layout of the current CHG setup and the planned pump-probe experiment in DELTA.

with stepper motors and mounted in the vacuum chamber of BL3 a few meters after M_1 and M_2, respectively. The diffuse reflection of laser light from the screens is viewed by two CCD cameras. Secondly, the mirrors M_1 and M_2 are adjusted such that the maximum light intensity is delivered to a powermeter in the diagnostics hutch (Fig. 3). The transmitted light intensity is mapped as a function of the vertical and horizontal orientations of the mirrors using the EPICS control system. This map shows the range of valid mirror settings at which the laser beam is not clipped by apertures. Additionally, a CCD camera with a long-focus lens looks upstream into the undulator chamber. The transmission can be judged qualitatively from the beam shape and the absence of reflections off the chamber walls. The setup of the diagnostics at BL4 is shown in Fig. 3. A He-Ne laser is used to pre-align all components.
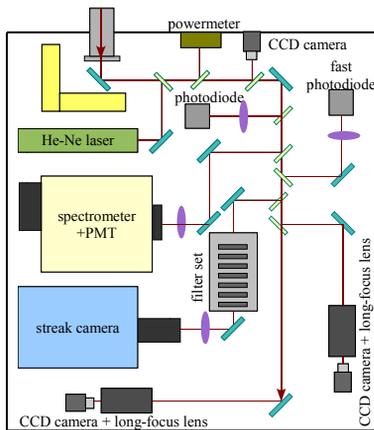

Figure 3: Schematic view of the diagnostics setup.

Transverse Alignment

In order to achieve transverse overlap, two different points inside the undulator are monitored by two CCD cameras together with 70-300 mm zoom lenses. One camera is focused at the beam waist at the center of the modulator, the other several meters downstream of the modulator. During machine studies, the electron orbit can be adjusted to match the optimized laser axis; otherwise the mirrors (M_1, M_2) in the seeding beamline are moved with a resolution of 0.5 µrad while observing the overlap of laser and undulator radiation on both CCD cameras. A clear distinction between laser and undulator light is made

by using a 1 Hz chopper in the laser path before entering the undulator. Figure 4 displays sample pictures of both CCD cameras with and without laser. A motorized mirror alternates between the two CCD cameras, since it was found that a beam splitter distorts the images.
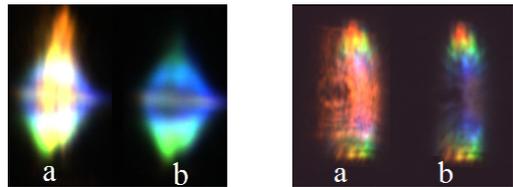

Figure 4: Images of CCD cameras focused to a distance of 14 m (left) and 7 m (right) with (a) and without (b) laser.

The accuracy of the transverse overlap in the modulator depends on the shape and quality of the CCD images. It is of the same order of magnitude as the long-term stability of the electron orbit (approx. 10-20 µm) in the modulator. Tuning the modulator and radiator to different colours helps to increase the accuracy of this method.

Timing

The laser must be synchronized to the reference radio frequency of 499.8 MHz. The frequency of the laser oscillator is locked to RF/6 ≈ 83.3 MHz and the phase shift is continuously measured and controlled. The revolution frequency of DELTA is 2.6 MHz and the harmonic number is 192. The signal RF/192 is sent to a delay generator which creates a 1 kHz signal to trigger the pump laser and the Pockels cells of the laser amplifier. The laser light and synchrotron radiation are collected by a fast photodiode detector, and the delay is measured by an oscilloscope with 2 GHz bandwidth.
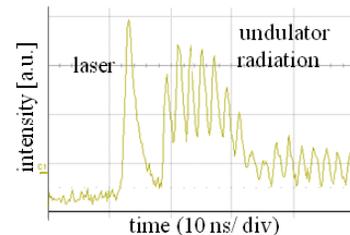

Figure 5: Oscilloscope trace of a photodiode signal showing a laser pulse and synchrotron light from electron bunches in multi-bunch mode, some of them with enhanced bunch current.

02 Synchrotron Light Sources and FELs

Figure 5 shows an example of a measurement with a delay of ~10 ns between the laser signal and the electron bunch train. After adjusting the laser timing, the remaining mismatch is less than a few 100 ps. For more accurate synchronization, a 2-GHz phase shifter with a resolution of 0.1° is used to finely tune the delay between the electron bunch and laser pulse, while the laser and synchrotron light is monitored by a streak camera with a temporal resolution of 2 ps. Figure 6 shows an image recorded by the streak camera. The apparent large duration of the laser pulse is due to space charge effects at the photocathode of the streak camera.
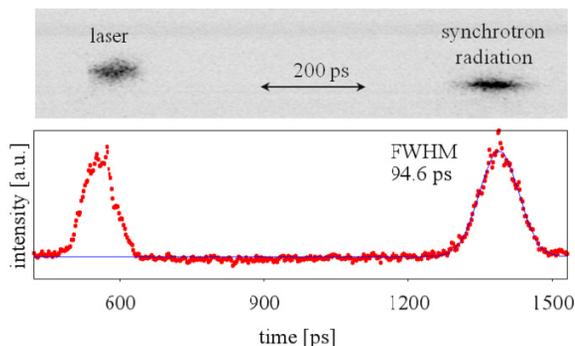

Figure 6: Image from a streak camera showing a laser pulse and an undulator radiation pulse with a remaining mismatch of ~800 ps.

OTHER DIAGNOSTICS

The CHG light is detected by a photodiode equipped with a band-pass filter [5], and its spectrum is measured using a Czerny-Turner type spectrometer with a photomultiplier at its exit slit [3]. Although a CCD spectrometer is available, the photomultiplier is used in order to resolve the signals from a single revolution (384 ns) that contains the laser pulse (1 kHz repetition rate), while the CCD spectrometer integrates over many turns.

THz radiation can be used as a sensitive measure for the energy modulation in the undulator. The THz signal, which is extracted by BL6 and detected by an In-Sb bolometer, is maximized by changing the vertical and horizontal orientations of mirror M_2.
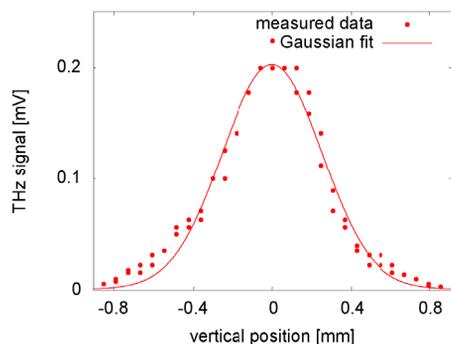

Figure 7: THz signal versus calculated position of the laser beam at the center of the modulator.

Figure 7 shows a scan of the vertical laser beam position while recording the THz signal. The width of the nearly Gaussian distribution is a convolution of the laser and electron beam size.

OUTLOOK

In the next CHG experiments, it is planned to use an IQ-vector modulator for more convenient temporal tuning. Additional methods are investigated to improve the transverse overlap diagnostics. An optical cavity, either newly built in the diagnostics hutch or from a former storage-ring FEL in the vacuum chamber around the U250, would create a symmetric pattern once laser and undulator radiation is collinear with the cavity axis. Furthermore, BL5 will be used for measuring the CHG spectrum at higher harmonics. The pump-probe experiments will be performed at BL5, which is equipped with a monochromator operating at photon energies between 15 and 750 eV. The horizontal spot size is ~700 µm; the vertical focal point and spot size are adjustable by the refocusing mirror, down to 70 µm. The extracted CHG beam from BL5 will be used as the probe pulse. The pump pulse should have a larger size than the probe beam for a sufficient spatial overlap and uniform heating of the sample. The angle between pump and probe pulse should be as small as possible because a non-zero angle causes a relative delay which depends on the transverse position. In a newly constructed laser hutch adjacent to the BL5, a delay stage with a maximum travel length of 600 mm and a resolution of 1.25 µm will be placed. A commercial position control system will be used to stabilize the transverse overlap between pump and probe pulses on the sample with an accuracy of 1 µm in position and 1 µrad in angle. At the moment, a spin- and angle-resolved photoemission spectroscopy (PES) setup with a spin-polarized low electron energy diffraction (SPLEED) detector and a delay line detector (DLD) is available at BL5 [6], which will in future be employed for pump-probe experiments with ultrashort pulses.

ACKNOWLEDGMENTS

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02 Synchrotron Light Sources and FELs