INDIRECT MEASUREMENTS OF NIR AND UV ULTRASHORT SEED LASER PULSES USING A TRANSVERSE DEFLECTING RF-STRUCTURE

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Abstract

Seeding of free-electron lasers (FELs) using external coherent optical pulses recently became an area of interest as users demand spectrally and temporally coherent FEL radiation which is not achievable in traditional self-amplified spontaneous emission operation mode. Since temporal and spectral properties of the seed laser pulses are directly imprinted on the electron bunch, a proper characterization of these seed pulses is needed. However, the lack of any measurement technique capable of characterizing ultrashort seed laser pulses at the laser-electron interaction region is a primary drawback. In this paper we report indirect measurements of seed laser pulses in an undulator section using a transverse deflecting RF-structure (TDS) at the free-electron laser FLASH at DESY. Temporally chirped and unchirped seed pulse length measurements will be compared with second-harmonic generation frequency-resolved optical gating measurements and theoretical simulations. Using this technique we will demonstrate that pulse artifacts such as pre- and post-pulses in the seed pulse in the femtosecond and picosecond timescales can be identified without any temporal ambiguity.

INTRODUCTION

External seeding techniques such as High Gain Harmonic Generation (HGHG) [1] and Echo-Enabled Harmonic Generation (EEHG) [2] have been demonstrated recently. Proper characterization of seed laser pulses in the interaction region, namely the undulator, is important for successful operation of such seeding schemes. However, to best of our knowledge, currently there is no technique available to directly measure the pulse duration of the seed laser pulses inside the undulator. In this study we provide indirect measurements of ultrashort laser pulses, using a technique which utilizes the energy modulation of an electron bunch due to seed laser beam, observed using a transverse deflecting RF-structure.

EXPERIMENTAL SETUP

Seed Laser System

The seed laser system (Fig. 1) employed in the FLASH1 seeding project is a solid-state, commercial, Ti-sapphire system based on chirped pulse amplification technique (CPA). The 108.3 MHz optical oscillator is synchronized to the master laser oscillator (MLO) via a RF-based link with a 50 fs rms jitter. A two-stage amplifier section is used to amplify the pulse energy up to 50 mJ/pulse at 10 Hz repetition rate and 800 nm centre wavelength. Amplified pulses are then extracted from the cavity and compressed down to 50 fs full width at half maximum (FWHM) duration. Pulse duration is measured using a commercial GRENOUILLE setup [3]. After compression, the pulse energy is 35 mJ/pulse with ± 2% rms stability.

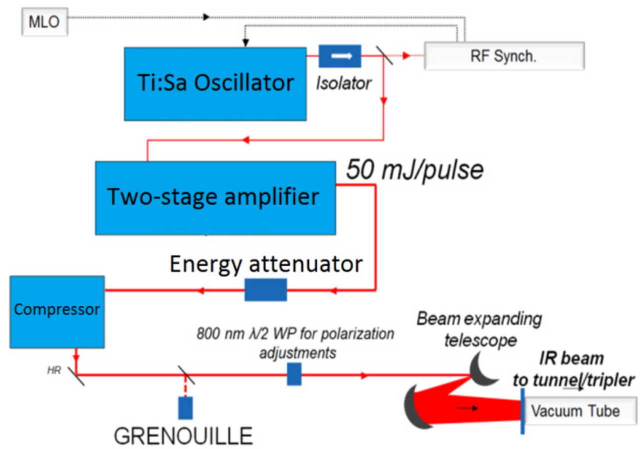

Figure 1: Schematic of the seed laser system at FLASH1.

Beam Delivery

The fundamental 800 nm beam is then delivered to a frequency tripler unit in order to generate the third harmonic of the fundamental beam for seeding. The in-coupling beam line consists of 3 m of air and 1 mm thick fused silica window prior to a high vacuum region of 10^{-6} mbar and 9 m in length. To keep the B-integral below unity the beam diameter is expanded by a factor of 3, from 6 mm FWHM after the amplifier to 18 mm FWHM after the beam expander.

Frequency Upconversion and Injection

Frequency tripling is performed using two β-Barium borate (BBO) crystals. First BBO crystal converts the fundamental frequency to its second harmonic and subsequent α -BBO delay plate adds a temporal delay to the fundamental pulse as both pulses need to be temporally overlapped in the second β-BBO crystal for efficient third harmonic generation. Polarization state of the fundamental beam is adjusted using a quarts waveplate λ/2 @ 800 nm and λ @ 400 nm. The conversion efficiencies for the second and third harmonics are approximately 20 % and 9%, respectively (Fig. 2). Estimated pulse duration of the third harmonics is approximately 150 fs FWHM.

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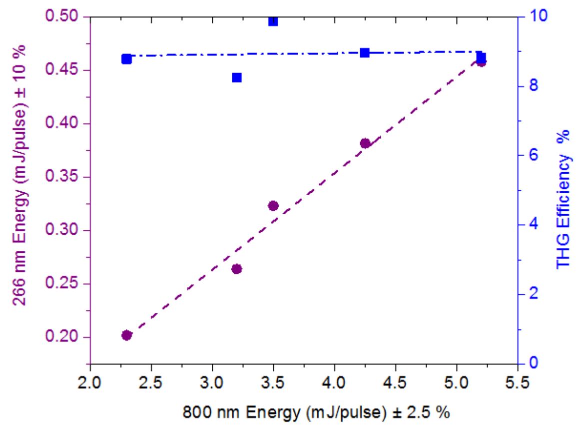

Figure 2: Measured third harmonic pulse energy (left axis, •) and conversion efficiency (right axis, ■) as a function of fundamental pulse energy. Due to generation of non-linear effects the fundamental beam energy is kept below 5 mJ/pulse.

The frequency upconverted seed beam is delivered to the electron beam trajectory using three-wavelength (800, 400, and 266 nm) mirrors. All three wavelengths are injected due to ease of obtaining the laser-electron overlap and the possibility of using the same setup for the SASE suppression experiment [4].

Electron Beam

A single bunch electron beam at 10 Hz repetition with a root mean square (rms) length of few picoseconds is used for at the initial stage to achieve proper overlap between the electron bunch and the seed laser pulse. Electron energy is 700 MeV with a peak current of 300 A.

Spatial and Temporal Overlap

Metal, Ce:YAG, and OTR screens are used for the transverse overlap. Course temporal overlap between laser and electron beam is first observed using a photo multiplier tube with a few hundred picoseconds accuracy and then using a streak camera with an accuracy of few tens of picoseconds. In order to achieve the overlap, the timing of the seed laser oscillator is shifted by means of a vector modulator. Final overlap is established using a transverse deflection structure (LOLA-TDS).

LOLA-TDS at FLASH

The LOLA transverse deflection structure at FLASH consists of a transverse RF deflector to project the longitudinal electron bunch into transverse coordinates and a magnetic dipole to resolve the energy, thus providing an image of energy deviation of the electron bunch as a function of longitudinal position inside the bunch [5, 6]. The location of the hardware is shown in Fig. 3. With proper calibration this image can be converted into energy deviation as a function of time. Once the longitudinal and transverse overlap between the two beams is established the seed laser provides an energy modulation to the electron bunch which can be observed in the LOLA image as a peak structure. As the width of this energy modulation depends on the seed laser pulse duration this image is used in our experiment to estimate the pulse duration of the seed laser inside the undulator section.

EXPERIMENTAL OBSERVATIONS

Fig. 4(a) indicates an energy modulated electron bunch due to overlap with the 800 nm seed pulse of 200 fs where Fig. 4(b) indicates an energy modulation due to 60 fs FWHM pulse. Once the images are calibrated (Fig. 4(c)) this indicates approximately 90 FWHM pulse duration inside the undulator. This pulse broadening is due to slippage and dispersive elements after the tripler such as vacuum window and mirrors. Also, pulse artefacts, such as pre- and post-pulses in the seed laser beam are clearly visible in these images which are not measurable without a temporal ambiguity using a standard ultrashort pulse measurement technique based on second order non-liner effects. Moreover, this technique could be utilized to simultaneously measure the pulse duration of seed laser pulses with different wavelengths.

SUMMARY AND OUTLOOK

In this paper we demonstrated that the LOLA-TDS at FLASH can be used to indirectly measure the ultrashort seed pulse duration inside the laser-electron interaction region. This is important for seeding experiments as there is no other measurement technique available to make such a measurement inside an undulator. This technique is being further investigated as a diagnostic for improving the efficiency of external seeding schemes.

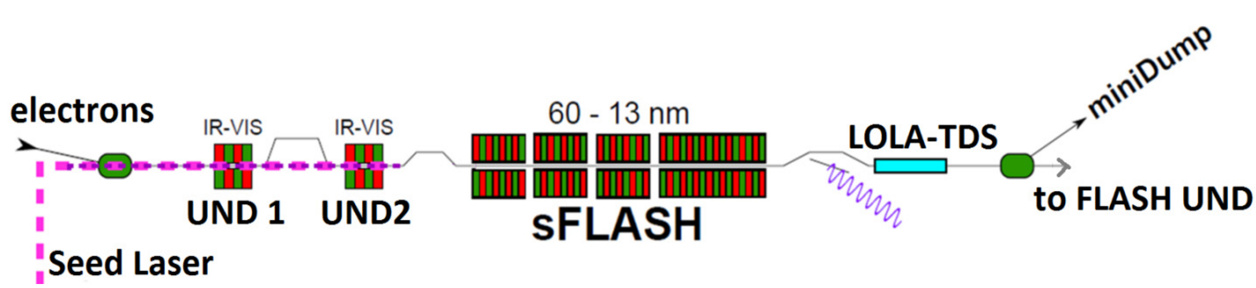

Figure 3: Arrangement of the FLASH1 seeding section.

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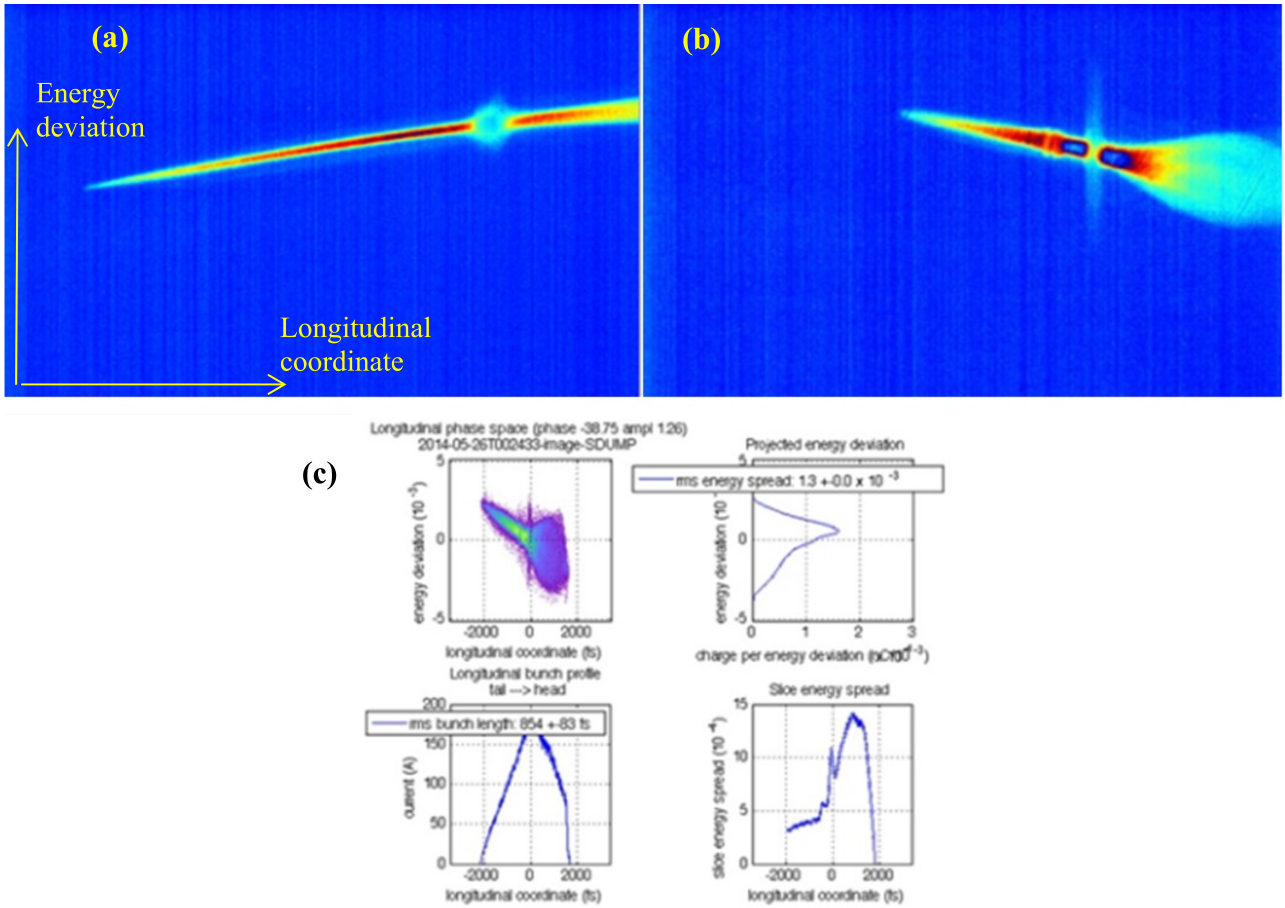

Figure 4: Retrieved images of LOLA-TDS structure once the laser-electron overlap is established. (a) Compressed electron bunch modulated by an 800 nm seed laser pulse of 200 fs FWHM measured after the tripler. (b) Modulation with 800 nm laser with 60 fs duration. Width of the large amplitude spike (3.5 MeV modulation) is related to the seed laser pulse duration. The calibrated image gives laser pulse duration of approximately 90 fs FWHM. Right side of the image indicates the front of the electron bunch. The smaller modulation of 100 keV is visible in the image and corresponds to a post laser pulse. (c) A calibrated LOLA image.

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