ATTOSECONDS AT HARMONICS AT THE EUROPEAN XFEL: FIRST RESULTS AT SASE3

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Abstract

We report on the observation of a substantial amount of single-spike spectra collected at the SASE3 beamline of European XFEL using a two-stage scheme (3 - 11 % with respect to all events). The undulators at the first stage were set to the resonance at the "fundamental", and the undulators at the second stage operated at the "harmonic" of the fundamental, in this case, it was the 4th harmonic. In the experiments, we expected radiation generation in the second stage to start from the high level of bunching created in the first stage. Moreover, the nonlinear characteristic of harmonic bunching growth rate at the first stage leads to the most rapid growth of the most prominent spikes. After being amplified at the second stage this provides occasional single spike pulses in the time domain. With that, we expect these single spike events in the spectrum correspond to single spike events in the time domain. We estimated *the minimal possible* pulse duration for these pulses using Fourier transform of the experimental spectra amplitude where we assume a flat phase across a pulse spectrum. The typical duration was at the level of several hundreds of attoseconds (300-500 as). Considering the appearance frequency of single spike events, this method may be attractive for high repetition-rate free electron lasers for generating sub-femtosecond radiation pulses.

INTRODUCTION

High bunching at harmonics driven by the fundamental has drawn the attention of researchers in the past and described in numerous publications, e.g. [1–3]. Underling effect consists in the fact that, the longitudinal phase space of the electron beam buckets "rotates" from nearly sin-like shape at the beginning of linear regime to a set of "strokes" in deep linear regime. This enhances the content of higher harmonics. The growth of bunching at harmonics is rapid and it reaches very shortly a sufficient level. This process is non-linear and is characterized by a power law dependence with respect to the fundamental ($b_n(t) \sim b_1^n(t)$), Fig. 1, where b_n denotes the bunching at the corresponding n-th harmonic.

Due to this power law dependence, spikes of bunching along the electron beam length are effectively being filtered: suppression of low value of bunching, increase of contrast, and reduction of the width of the spike follow, as depicted in Fig. 2.

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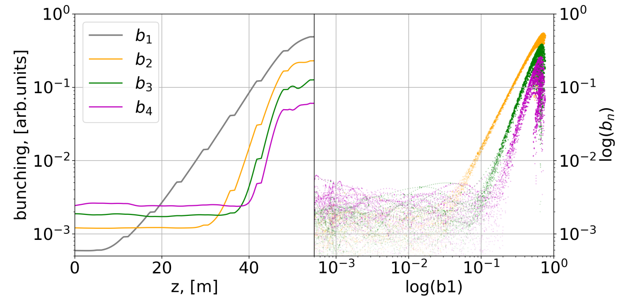
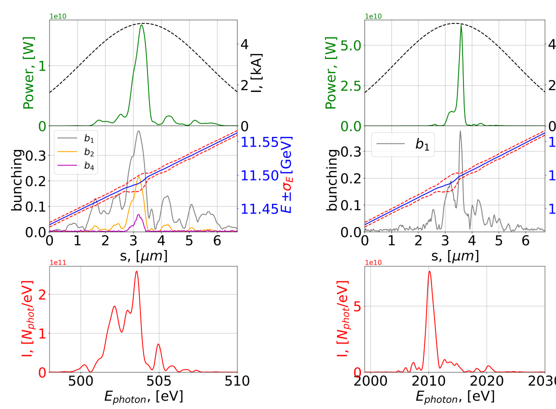


Figure 1: Simulation of the growth of the harmonics bunging with GENESIS 1.3 code, [4]. Left: evolution of the bunching factor for the fundamental (1st), 2nd, 3rd, and 4rd harmonic. Right: dependence of the harmonics bunching factor on bunching factor at fundamental in log-log scale. The long plateau on the left corresponds to a negligible level of the higher harmonics content, followed by a linear dependence $b_n(t) \sim b_1^n(t)$, the slopes of the lines is $2, 3, 4$ for the corresponding harmonics, which corresponds to linear regime, on the right a hook-like dependence represents saturation.



(a) (b)

Figure 2: A first part of the FEL is tuned at the fundamental harmonic (a), while a second part lases at the fourth harmonic with respect to the first stage (b). The spikes of the harmonics were effectively filtered when compared to the bunching distribution of the fundamental harmonic. One may observe suppression of low values of bunching, increase in contrast, and reduction of the width of the spike.

The authors of [5] proposed to use this effect for generating sub-femtosecond pulses with two (or *multi*) stage

FIRST LASING OF THE THz SASE FEL AT PITZ*

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Abstract

The Photo Injector Test Facility at DESY in Zeuthen (PITZ) develops a prototype of an accelerator-based high-power tunable THz source for pump-probe experiments at the European XFEL. The PITZ injector is also the site for the development and preparation of the high-brightness electron source for the main linac of the European XFEL and has the same pulse train structure as the X-ray photon source of the XFEL. For the proof-of-principle experiments on high-power THz generation an LCLS- I undulator (on loan from SLAC) is installed in the tunnel annex downstream of the existing accelerator. The extension of the beam line consists of a bunch compressor and a collimation system in the main PITZ tunnel, as well as a matching section, the undulator and the THz diagnostic setup in the tunnel annex. A Self-Amplified Spontaneous Emission (SASE) FEL is used to generate the THz pulses. High radiation power can be achieved by utilizing high charge (up to several nC) electron bunches from the PITZ photo injector. A beam energy of ~17 MeV is used to generate THz radiation with a centre wavelength of 100 μm. The transport of this space charge dominated electron beam and its thorough matching into the planar LCLS-I undulator with a strong vertical focusing is one of the project challenges. The installation of the first THz beamline setup was finished in summer 2022 and commissioning with electron beam started. A specially developed procedure for a high charge beam matching into the undulator was successfully tested resulting in a first THz pulse generation. The start-up THz diagnostics is based on pyrodetectors. First measurements of the THz generation from 1 nC, 2 nC and 3 nC bunches have been taken, the statistics properties analysis corresponds to the expected SASE performance. The gain curve for the 3 nC case reflects the onset of saturation regime.

INTRODUCTION

The Photo Injector Test Facility at DESY in Zeuthen (PITZ) currently develops a prototype for a high-power tunable accelerator-based THz source for pump-probe experiments at the European XFEL [1]. A promising concept to provide THz pulses with a pulse repetition rate identical to that of the X-ray pulses is to generate them using the PITZ photo injector. Because PITZ develops the high-brightness electron source for the European XFEL, properties of the photo injector are fully compatible with the XFEL one, especially both injectors maintain the same pulse train structure. To generate a high-power THz pulses a SASE FEL is considered as a main mechanism. One of the key parameters for the THz SASE FEL high performance is a high beam peak current of up to 200 A. The PITZ RF-gun with a Cs_2Te photocathodes is capable of generating electron bunches with charges of up to several nC (up to 5nC), making it suitable for the proof-of-principle experiments on the high-gain THz SASE FEL. The THz beamline has been designed and implemented as an extension of the existing PITZ linac in the tunnel annex [2]. A planar LCLS-I undulator (on-loan from SLAC) is used to generate the THz radiation. The undulator parameters (period of 3 cm and undulator parameter of ~3.5) demand an electron beam energy of ~17 MeV for the centre radiation wavelength of ~100 μm. The strong magnetic field with a horizontal gradient requires a thorough beam matching. Another challenge is the narrow vacuum chamber (height 5 mm, width 11 mm, and length ~3.5 m), which makes matching and transport of the space charge dominated electron beams a complicated task.

The THz beamline was successfully commissioned [3] with 100 pC beams, then high-charge transport and matching started. A special procedure was developed and experimentally tested before at the existing part of the PITZ linac [4] and then successfully applied at the newly installed THz beamline. The first THz SASE FEL lasing was first detected with 1 nC bunch charge, then the bunch charge was stepwise increased to 3 nC. The gain curves were measured for 1 nC, 2 nC, and 3 nC.

THz BEAMLINE

The previously existing PITZ beamline was extended by a bunch compressor and a collimator system in the first tunnel and a matching system, the LCLS-I undulator and THz diagnostics in the second tunnel annex (second PITZ tunnel) downstream of the existing accelerator [2]. The current THz beamline in the tunnel annex is shown in Fig. 1. The THz radiation is measured using pyrodetectors at two stations after the undulator [3]. To measure gain

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