SEEDED COHERENT HARMONIC GENERATION WITH IN-LINE GAS TARGET

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Abstract

The test-FEL at MAX-lab already demonstrated seeded coherent harmonic generation down to 40 nm [1]. As a step further in the development of our seeding techniques, we plan to use a gas target to generate harmonics of the drive laser and seed the electron beam with them. In order to optimize the injection process, our aim is to place the gas target for harmonic generation as close as possible to the first undulator. In order to minimize the losses the transport of the drive laser is done with a minimal number of mirrors and there are neither focusing nor filtering elements between the harmonic chamber and the first undulator. The goal is to test whether the harmonic intensity in the undulator is high enough to induce full energy modulation of the electron beam. The wavelength range of the harmonics that will be used as seed is around 100 nm and we plan to detect the coherent harmonic signal of the second harmonic generated in the radiator. The flexibility of the setup will allow us to drive the harmonic generation process with the fundamental wavelength of the laser or the second harmonic or the combination of them. Adding the second harmonic will lead to the generation of even harmonics, thus increasing the range of seeding wavelength.

INTRODUCTION

Due to the increasing interest in seeding at short wavelengths and in the optimization of the injection process, we plan to implement a new configuration for seeding with harmonics generated in a gas target. The basic setup is borrowed from the test-FEL at MAX-lab, which already demonstrated seeded coherent harmonic generation (CHG) and variable polarization down to 40 nm [1]. Since our aim is to minimize the losses in the transport and focusing, the gas target for high-order harmonic generation (HHG) will be placed directly in front of the first undulator. Preliminary analytical estimations indicate that the co-propagation of the electrons with the drive laser and the harmonics should not degrade the quality of the electron beam. We expect to imprint full energy modulation to the electron beam which will lead to produce bunching at the fundamental wavelength and its higher harmonics. This can be demonstrated detecting the coherent harmonic signal of the second harmonic generated in the radiator. The whole setup is very flexible and it makes possible to drive the HHG process also with a combination of the fundamental wavelength and second harmonic, which opens to a better wavelength tunability.

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EXPERIMENTAL SETUP

The Test-FEL at MAX-lab

The test-FEL utilizes the injector for the MAX-lab rings and consists of two linac structures plus a recirculator that allows to reach almost 400 MeV after the second passage of the electron beam through the linacs (see Fig. 1). The thermionic gun is used as photocathode gun [3], with the heating almost turned off and the BaO cathode is illuminated by the second harmonic of a Ti:Sa laser. The bunch can be compressed mainly in the extraction chicane after the second passage through the linacs. Then a dog-leg lifts up the beam to the level where the undulators are placed.

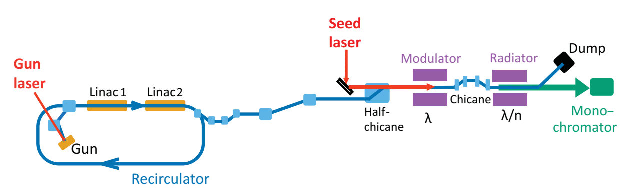

Figure 1: Layout of the experimental setup.

Before the first undulator (modulator) a half-chicane allows to insert an external laser for seeding. The second undulator (radiator) has different period length. In between the undulators a small chicane is used both for producing some bunching and for stopping the seed laser (if needed). After the second undulator the electron beam is bent to the beam dump while the radiation produced is detected by a spectrometer. More details about the setup and the undulator parameters can be found in [1, 2].

The typical parameters of the electron beam for the test-FEL operations are shown in Tab. 1.

Table 1: Electron Beam Parameters

Energy	375 MeV
Charge	40 pC
Bunch length	1 ps
Energy spread	$0.5 \cdot 10^{-3}$

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The New Drive Laser

The drive laser is a diode pumped dual stage kHz Ti:sapphire system. The first stage, a regenerative amplifier, is installed on a carbon fiber base plate resulting in improved beam stability for both vibrational and thermal effects. Both amplifier stages have cryo-cooled crystals further improving stability and flexibility to pump laser conditions. Main laser performance parameters are listed in Tab 2. Both gun laser and seed laser oscillators are locked to the 2.998775 GHz main accelerator RF, distributed through a low-loss coaxial cable.

Table 2: Seed Drive Laser Performance

KMlabs dual stage Wyvern-1000	
Pulse energy	8 mJ
Pulse duration	45 fs
Repetition rate	1 kHz
Pulse-pulse energy fluctuation	1% RMS

Harmonic Generation Source for Seeding

The test-FEL has been already commissioned in 2010 and seeding with a conventional laser at 263 nm has been demonstrated. In our new setup the seed laser will be replaced by a HHG source. Among different configurations, all aimed to minimize the optics for the laser transport, we have chosen the one in Fig. 2. The HHG chamber is placed about 1 m from the entrance of the first undulator (modulator). The electron beam co-propagates with the driving laser and passes through the 10 mm long, 1 mm diameter, Xe-filled gas cell where the harmonics are generated. The generated harmonics co-propagate with the driving field and the electron beam in the forward direction, i.e., into the modulator, without any additional refocusing. The system relies on the focusing of the infrared beam, which is done before the insertion in the vacuum pipe about 10 m upstream with two curved mirrors.

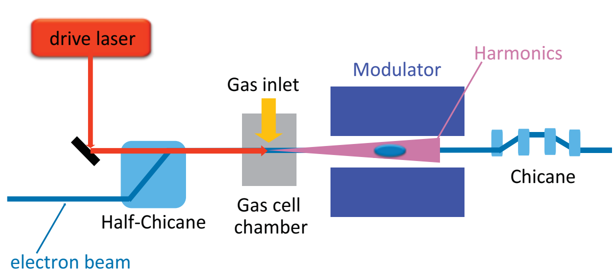

Figure 2: Layout of the HHG seeding arrangement.

This direct way of seeding the electron beam also features no filtering of the HHG comb: all the harmonics are sent together with the infrared laser beam into the undulator without passing through a monochromator or filter. All the light is stopped in the magnetic chicane before the radiator. Although we intend to optimize the HHG source for low harmonics (around 100 nm) to match the low energy of the electron beam, the setup can be used to generate much higher harmonic orders. The expected energy of the selected harmonic from the gas cell is at least 1 μJ. The configuration chosen will allow to easily change the drive laser from 800 nm to 400 nm by means of a thick BBO crystal and we could also use a combination of the fundamental and the doubled frequency, which has been shown to enhance the output power [4].

New Diagnostics

In order to characterize the HHG radiation after the seeding, a new spectrometer equipped with MCP detector will be placed in the chicane section between the undulators. A new extraction chamber with a 45° mirror has been designed to couple out the seed laser and the harmonics while the electron beam is deviated from the straight path. The drive laser will be removed in the chicane to avoid contamination in the second spectrometer which is placed after the radiator and which is the main diagnostics for the CHG process.

EXPECTED PERFORMANCE

The field of the seed modulates the energy of the electron beam when they are coupled with the magnetic field of the first undulator. The energy modulation is converted into bunching when the electrons pass through the magnetic chicane. The second undulator will be tuned to the second harmonic of the seed and we expect to detect radiation from CHG at the 50-65 nm.

The Effect of Infrared Feld on the Electron Beam

One of the challenges of this project consists in preserving the quality of the electron beam despite the interaction with the very strong infrared field in the modulator. Unfortunately the 3D FEL codes generally used for this purposes cannot simulate the interaction of the electron beam with a radiation with longer wavelength than the seed laser. However 1D simulations show that the effect of a lower harmonic field cancels out when the number of undulator periods is an integer multiple of the resonant harmonic number [5]. Of course this is not true for any other number of undulator periods and can lead to exotic bunching content. Although this is an interesting feature, one should keep in mind that 1D modeling neglects the diffraction of the infrared laser in the undulator.

HHG Simulations

The HHG simulations start from single-atom response in the laser field solving the time dependent Schroedinger equation. The macroscopic response is obtained taking into account atomic polarizabtiliy, free electrons, absorption, dispersion and beam geometry. This code has been benchmarked with experimental results [6] and fine-tuned for the case of very low harmonics.

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The amplitude and the phase of the sixth harmonic (equal to the third harmonic of the doubled frequency) HHG field is shown in Fig. 3 for a particular position along the pulse, close to the maximum of the intensity.

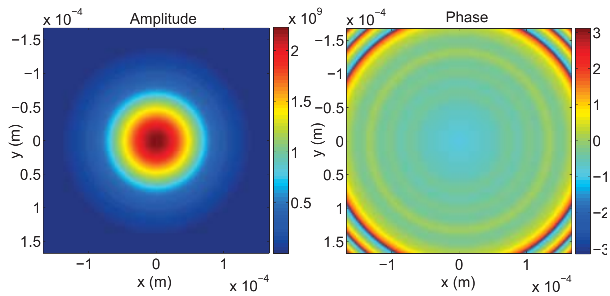

Figure 3: Amplitude and phase of the sixth harmonic at the maximum of the intensity.

FEL Simulations

We used the code developed by the Lund Laser Center to extract the complex field of the HHG pulse and with this we fed a time-independent GENESIS simulation. The induced energy spread by HHG creates bunching, as shown in Fig. 4 and thus indicates that a significant second harmonic content can be expected.

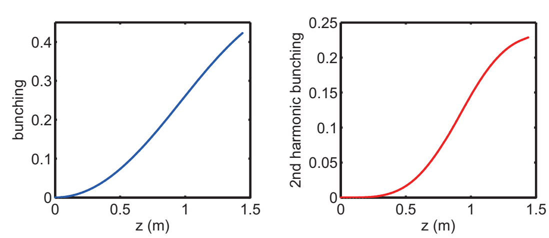

Figure 4: Bunching at the fundamental wavelength and its second harmonic along the modulator.

Further studies are on going in order to model the electron beam and the radiation field in more details. Besides time dependent simulations are envisaged to determine eventually the expected energy of the CHG radiation.

CONCLUSIONS

In this paper we presented the status of the HHG seeding project at the test-FEL at MAX-lab. Various challenges will be addressed by this new in-line setup: the electron beam has to propagate collinearly with the drive laser inside the HHG chamber, the harmonics will not be filtered and the drive laser will shine in the first undulator. Preliminary estimations show that the influence of the infrared field on the electron beam (and the CHG process) should be negligible. Besides only the harmonic in resonance with the magnetic field of the undulator will interact with the electron beam. The new setup will be implemented during this fall and the commissioning will follow.

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