THE TEST-FEL AT MAX-lab: IMPLEMENTATION OF THE HHG SOURCE AND FIRST RESULTS

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Abstract

The test-FEL at MAX-lab is a development set-up for seeding techniques. After the successful demonstration of coherent harmonic generation from a conventional laser, the new layout now presents a gas target for generation of harmonics. The drive laser will be up-converted and the low harmonics (around 100 nm) will seed the electron beam. The energy modulated electrons will then be bunched in the dispersive section and will radiate in the second undulator. We will detect the second harmonic of the HHG radiation around 50 nm. This experiment has several challenges never tried before: co-propagation of the electron beam and the drive laser, interaction of the electron beam with the gas in the target, no-focusing of the harmonics and no drive laser removal. The commissioning will show if this kind of in-line chamber has advantages with respect to more traditional approaches with optical beam transport. The results are relevant for many facilities that are planning to implement HHG seeding in the near future.

MOTIVATIONS

Seeding a Free-Electron Laser (FEL) with a High Harmonics Generation (HHG) source was firstly demonstrated few years ago [1]. Since then, only a few facilities [2, 3] have tried to implement this technique in a rather conventional way. One of the main challenges lies on the transport and focusing of the harmonics from the emission point to the undulator, where the interacting with electrons happens. The geometry of the accelerators and the radiation safety infrastructures often limit the optimization of the path. Ideally one would like to minimize the number of optical components (mirrors and lenses) from the drive laser (usually an infrared Ti:Sa system) to the gas cell and also limit the optics after the gas cell that are needed for the transverse overlap with the electron beam.

Our idea is to place the HHG source directly in front of the first undulator (modulator), in-line with the electron beam. In this way one can eliminate all optics after the emission of harmonics. The idea behind this is that the harmonics inherit their divergence from the drive laser, so if the production point is very close to the beginning of the undulator, they basically don't need refocusing. An extension of this setup would be possible for any wavelength, because the transport is not limited by the bandwidth of the optics. In this way the tunablity of the FEL source will be limited only by the separation between the (high) harmonics.

The last (but not least) motivation for this experiment is the possbility to achieve modulation of the electron beam at a certain wavelength and generation of higher harmonics in the second undulator (radiator). The combination of HHG source with modulator/dispersive section/radiator has never been tested before (although separately they have been already demonstrated). Due to limitations in the diagnostics we will be able to detect only the second harmonic (at about 50 nm) of the selected HHG line, but this will be sufficient to demonstrate the principle.

EXPERIMENTAL SETUP

The HHG Source

The HHG source is based on a Ti:Sapphire laser system able to provide 8 mJ in 45 fs pulse duration. The repetition rate is up to 1 kHz, but for the seeding the electron beam maximum 2 Hz will be used. The drive laser is locked to the 3 GHz accelerator RF. The HHG chamber has been designed as a duplicate of a working device at the Atomic Physics department in Lund. The main feature is that the drive laser and the electron beam are both passing through a small hole (1-2 mm) which is the gas cell. In Fig. 1 the geometry of the gas target is shown. The additional advantage of our setup is the possibility to change the frequency of the drive laser, using either the infrared beam or converting it with a crystal to 400 nm.

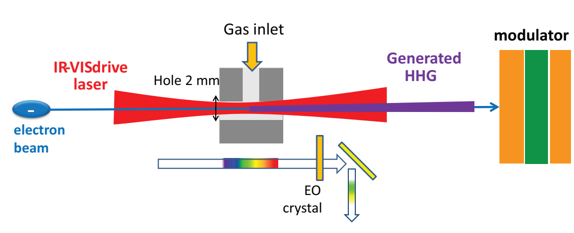

Figure 1: Layout of the HHG source with the path of the electron beam and the drive laser.

Since the testFEL section is connected to the MAX-lab injector, a differential pumping system has been added upstream of the HHG chamber. It consists of a small tube 15 cm long with an inner diameter of 5 mm. Two turbo pumps are equipping the HHG chamber and the nearby

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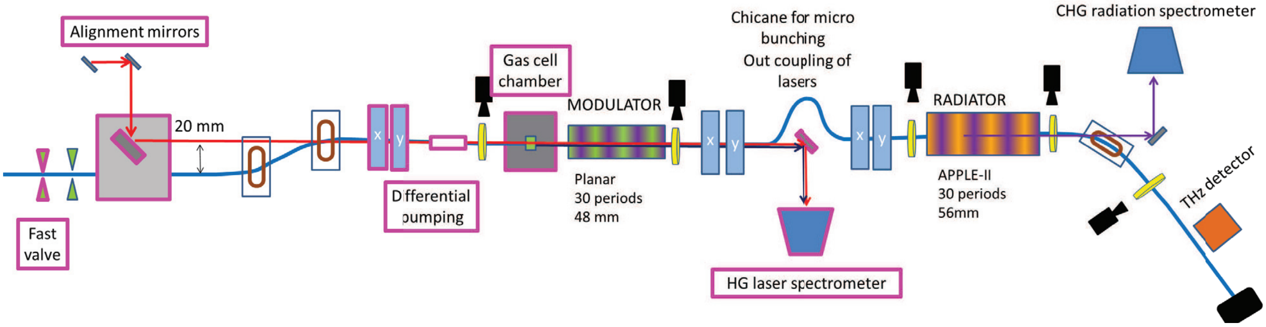

Figure 2: Layout of the test-FEL at MAX-lab. The electron beam is coming from the left. New components are marked in pink.

vacuum pipe. A fast-valve is used to protect the upstream part of the injector in case of pressure increase after the differential pumping. This is one of the main differences between the operations of an HHG source in the accelerator environment and in a laser laboratory.

Summarizing the prominent features of this setup:

- in-line chamber
- no focusing of harmonics
- no filtering/monochromatization
- no drive laser removal
- optimization of low harmonics
- drive laser at 800 and/or 400 nm.

The Test-FEL at MAX-lab

The electron beam is produced by the same injector used at MAX-lab to fill the three storage rings. The same RF gun is used as photocathode gun for the FEL operations [4]. The final energy is about 400 MeV and the bunch charge transported until the beamdump around 40 pC. Using the exiting chicane and the dogleg, it is possible to compress the bunches. The upper limit for the bunch length can be measured using the EO-crystal (see Fig. 1). Using this method, a bunch duration of 1 ps has been achieved [5]. A few years ago the test-FEL at MAX-lab demonstrated variable polarization VUV radiation using a conventional laser as seed [6].

Figure 2 shows the test-FEL beamline with particular emphasis on the improvements and changes with respect to the previous setup, before the implementation of the HHG source. The new components installed during last year are: a fast valve, new alignment mirrors for the drive laser, a couple of streering magnets, the differential pumping, the gas chamber and the HHG spectrometer.

RECENT EXPERIMENTAL RESULTS

We started the commissioning of the HHG source during June 2013. Following the promising results of single-atom response simulations [7], it has been decided to double the frequency of the Ti:Sapphire laser to generate 400 nm light. This radiation has been used as driver for the HHG source. Starting from blue light, one can use for the seeding the third harmonic at 133 nm.

The first signal of harmonic generation has been generated using Xenon and Argon. The HHG diagnostics is done with an in-vacuum spectrometer placed on top of the dispersive section (see Fig. 2). The HHG radiation is brought up with a periscope with the help of two silver coated mirrors. Mirrors also remove the drive laser so it does not leak into the radiator. The spectrometer uses an MCP detector and we coupled a CCD camera. The pictures in Fig. 3 show the signal from the spectrometer with the gas off and with the gas on. The spectrometer was set to 133 nm. The background signal on the left picture is due to the drive laser.

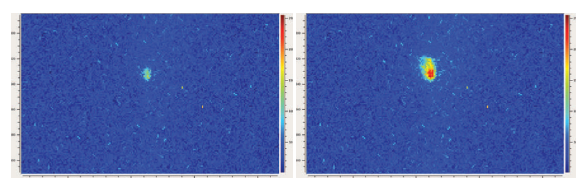

Figure 3: Comparison of CCD images. Left: spectrometer signal without gas. Right: spectrometer signal with gas on. Aperture time 600 ms, 10 Hz repetition rate.

Additional Tests

Other additional tests were performed in order to rule out possible side-effects from the co-propagation of electrons and laser within the gas cell. In particular, we tested if the presence of the gas in the small cell can cause disturbances in the electron beam. As monitor, we used the YAG screen downstream the HHG source, after the modulator. The transverse section of the electron beam has been monitored during aperture and closure of the gas. A further test has been the interaction of the seed laser with the electron beam. In both experiments, no macroscopic differences have been observed, however as the correct timing will be found only with the simultaneous occurence of HHG radiation and electron beam, this results are just preliminar. The final test would be to check if the electron beam can pre-ionize the gas, disturbing the HHG process. Preliminary considerations show that the electron beam should not disturb the emission of harmonics.

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CONCLUSIONS AND OUTLOOK

An HHG source has been installed at the test-FEL at MAX-lab and the commissioning started in June 2013. The aim of this experiment is to demonstrate that an in-line chamber, placed in front of the modulator is an alternative setup for seeding with HHG. With the HHG source, we managed to produce and detect the third harmonic at 133 nm of the 400 nm drive laser. We plan to resume the experimental activies in mid-september 2013 and conclude before the end of the year. Finally we want to demonstrate full energy modulation by HHG source and the creation of coherent harmonics.

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