sFLASH - FIRST RESULTS OF DIRECT SEEDING AT FLASH*

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Abstract

The free-electron laser facility FLASH at DESY (Hamburg) was upgraded during a five month shutdown in winter 2009 [1]. Part of this upgrade was the installation of a direct seeding experiment in the XUV spectral range. Besides all components for transport and diagnostics of the photon beam into and out of the accelerator environment, a new 10 m long variable-gap undulator was installed upstream of the existing FLASH undulator system. The seed pulses are generated within a noble-gas jet by focusing 40 fs long Ti:Sa laser pulses into it, resulting in a comb of higher harmonics. In the first phase of the experiment, the 21st harmonic at about 38 nm will be used to seed the FEL process. The commissioning of the experiment has started in April. All hardware components are in operation and first seeding is expected for end of September 2010. The experimental setup and the commissioning procedures as well as first result are presented.

INTRODUCTION

The FEL user facility FLASH consists of a 1.2 GeV superconducting linac and 27 m long fixed-gap undulator, producing XUV pulses based on the SASE principle with variable pulse length. During the upgrade in 2009, some major modifications and installations of new components were made e.g. a new RF gun, a 7th accelerator module, new RF systems and 3rd harmonic superconducting RF cavities [2] to name but a few. In addition, 40 m of the electron beamline between the energy collimator and the existing SASE undulators were modified to install a new variable-gap undulator system for a direct seeding experiment.

Direct Seeding with High Harmonics

So far, XUV and X-ray radiation produced by FEL facilities was generated using the SASE principle to achieve high peak intensities at the GW level. In this operation mode the laser pulses consist of a number of uncorrelated longitudinal modes due to the start-up of the amplification process from shot noise of the electron bunch. The results are a reduced longitudinal coherence and shot-to-shot fluctuation. Another limitation for time-resolved user experiments is the arrival time jitter of the electron bunches and the photon pulses, respectively. Although some pump-probe experiments can measure the arrival time of each individual photon pulse with an acurracy of 40 fs (rms) to sort the experimental data afterwards [3, 4], this method has its own limitations. The obvious solution to have a high temporal resolution for pump-probe experiments is to get the pump and the probe pulses from the same source. If in addition the experiments need high XUV intensities a directly seeded FEL is presently a promising way to achieve these requirements. The XUV seed pulses for such an experiment are delivered by the generation of higher harmonics (HHG) of near-infrared (NIR) laser pulses in rare gases [5]. At FLASH the direct seeding with higher harmonics below 40 nm is presently under study and first pump-probe experiments with this seeded FEL will be performed soon. One of the key challenges of seeding is to establish the six-dimensional overlap between electrons and seed photons within the undulator, namely the transverse position and angle of both beams in the vertical and horizontal plane, the longitudinal overlap and the spectral overlap. In addition, a matched transverse beam size of photons and electrons guarantees an optimal utilization of the seed pulse energy.

EXPERIMENTAL SETUP

Detailed information of the experimental setup can be found in [6]. Here, details about the diagnostics to establish the six-dimensional overlap of photon and electron beam will be presented.

Transverse Overlap Diagnostics

Along the sFLASH undulator beamline several diagnostic tools are used to measure the transverse position and profile of the electron or the photon beam, respectively. Eight beam position monitors (BPM) and eight optical transition radiation (OTR) screens are used to measure the transverse electron beam parameters and to match the electron beam in the seeding undulator. Two OTR stations are equipped with the standard optics developed for TTF2. The others use specially designed solutions for the particular geometries, two at the diagnostic stations of the optical replica experiment (ORS) [7], and four in the sFLASH undulator (see also Fig. 1). In the latter case optics is also used to image a cerium-doped YAG crystal which converts

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the XUV radiation from the HHG source into visible light. With that, it will be possible to directly measure the transverse overlap of the XUV and the electron beam.

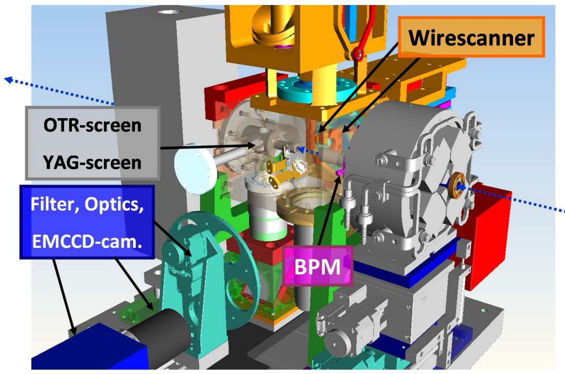

Figure 1: 3D Model of the undulator intersections. The electron beam travels from right to left, passing a quadrupol (adjustable transversly), a button BPM, horizontal and vertical wire scanners, a set of screens and a phase shifter. The latter corrects the gap-dependent phase advance from one undulator to the next.

Longitudinal Overlap Diagnostics

The temporal overlap of the electron bunches and the laser pulses will be found with using two methods. Firstly, a streak camera based approach will be employed that simultaneously measures the remnant 800 nm laser and undulator radiation from the electron beam. Later, a finer resolution ORS-based [7] system will be used in which the 800 nm laser imprints an energy modulation onto the electron beam, which will be used to produce a coherent radiation signal [8]. The streak camera is placed close to the electron beamline in a special shielded container to protect the electronics against radiation damages. A remotely controlled optical beamline guides the synchrotron light from an electromagnetic undulator and the 800 nm laser light to the entrance slit of the camera (see Fig. 2). Different sets of bandpass and neutral-density filters allow attenuating the two beams to get equal intensities within a certain bandwidth. The coarse temporal overlap (1 ns) will be measured with a photo-multiplier or a photo diode. Once the two pulses are found with the largest time window (500 ps) of the streak camera, the resolution can consecutively be increased to about 1 ps. From this point on, a fine scan of the temporal overlap with step sizes of a few ten femtoseconds will be done.

Undulators

sFLASH comprises a 10 m long variable-gap undulator section [9, 11]. With that, the sFLASH experiment can be operated independently of the electron beam energy which defines the FEL wavelength for the SASE undulator. During the commissioning period, the complete undulator system was tested. Beam-based orbit response measurements

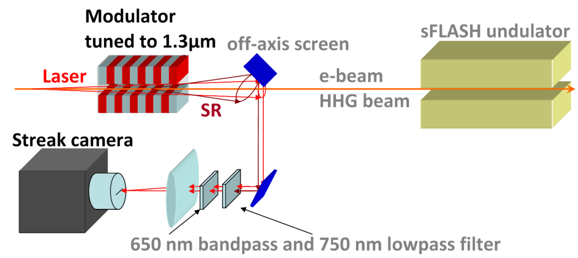

Figure 2: Sketch of the setup for the longitudinal laser-electron overlap. A short electromagnetic undulator radiates synchrotron radiation (SR), which is coupled out with an off-axis screen together with light from the HHG drive laser. Electron and HHG beam can pass to the sFLASH undulator.

for each undulator module for varying gap sizes were performed in order to create correction tables for horizontal and vertical air coils.

FEL Beamline and Photon Diagnostics

After the undulator section, the electron beam is vertically displaced by a magnetic chicane and the FEL radiation is extracted by a deflecting mirror, the horizontal position and tilt angle of which can be adjusted. The photon beamline continues with the first diagnostic block equipped with a Ce:YAG screen and two cameras, then a second switching mirror allows to send the radiation either into the diagnostic branch or to the experimental hutch. The roll angle of this mirror allows to steer the beam vertically. The diagnostic branch consists of a MCP-based intensity monitor using three different MCPs and different meshes [10], and a commercial XUV-spectrometer.

OVERLAP PROCEDURE

During the commissioning phase, the procedures to find the photon-electron overlap were tested with the aim to get the first direct seeding at 38 nm. The following sequence is used to guarantee that all beam properties are set correctly. The first step is to match the electron beam size along the sFLASH undulator and into the FLASH SASE undulator. Then, a transversely deflecting structure located downstream the sFLASH undulators is used to adjust the electron bunch length by changing mainly the RF phases of the first accelerating modules and the third-harmonic module. The aim is to use a linear compression scheme to achieve bunch lengths of the order of a few 100 fs with a peak current of about 1 kA or higher. In the next step, the electron beam orbit through the undulator is adjusted using a laser-based alignment method. The laser beam is aligned to the centre of the vacuum chamber and the beam position at each undulator intersection is marked on the OTR screens. Afterwards, the electron beam is set to these positions using upstream corrector steerers. Slow orbit feedback systems are switched on to assure that the beam orbit is constant at that position. The position of the HHG beam is also checked to be sure that the two beams are overlapped transversely. In the following step, the coarse temporal overlap is set using the streak camera setup described earlier. For that, the ORS modulator is tuned to 1.3 μm to couple out the second harmonic at 650 nm with an off-axis screen. Together with remnant light from the HHG drive laser these beams are filtered with a 750 nm lowpass and a 650 nm bandpass giving the possibility to adjust both beam intensities to the same level. With the streak camera, the arrival time difference of both pulses is measured with a resolution below 1 ps. Next, the spectral

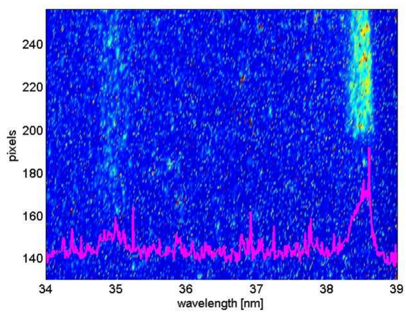

Figure 3: HHG spectrum on the XUV-spectrometer with an exposure time of 10 s. The 21st harmonic is visible at 38.5 nm.

overlap is set. For this purpose, the spectrum of the HHG is monitored on the XUV-spectrometer behind the undulator (see Fig. 3). Then, each undulator module is closed separately and the gap is tuned so that spontaneous emission matches the HHG wavelength. The complete undulator is closed to the measured gaps, while the orbit feedback ensures a constant electron beam trajectory. At last, a fine scan of the delay between photon and electron pulses is done using an electronical delay generator for the laser oscillator trigger. By changing the delay in 25 fs steps, the laser-electron overlap can be achieved.

FIRST RESULTS

One of the milestones of the project was the generation of FEL radiation in the SASE regime with the sFLASH undulator. Following the procedure described above, this milestone could be achieved after setting the spectral overlap. With the very first electron bunch passing the undulator, a collimated XUV beam was observed on the Ce:YAG screens in the diagnostic section (see Fig. 4). A first characterization of this radiation was performed. Figure 5 shows e.g. a single-shot SASE spectrum at around 38.5 nm wavelength. So far, no measurements of seeded FEL pulses could be performed. A first indication for a laser-electron interaction was observed. After the final commissioning of the optical synchronization system for the HHG source setup [12], the timing jitter of the electron with respect to the laser beam will be reduced.

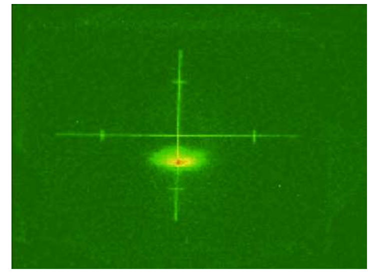

Figure 4: First SASE radiation from sFLASH on a Ce:YAG screen.

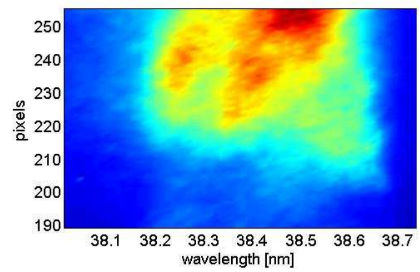

Figure 5: Single-shot SASE spectrum on the XUV-spectrometer after adjusting the spectral overlap.

SUMMARY

The commissioning of all components for the direct seeding experiment at FLASH has been started. All diagnostics to establish the six-dimensional laser-electron overlap and to diagnose seeded FEL pulses are in operation and show good performance. First seeding at 38 nm is expected during the next FEL study period.

ACKNOWLEDGMENTS

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