FIRST DIRECT SEEDING AT 38 nm*

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Abstract

The sFLASH project at DESY is an experiment to study direct seeding using a source based on the high-harmonic generation (HHG) process. In contrast to SASE, a seeded FEL exhibits greatly improved longitudinal coherence and higher shot-to-shot stability (both spectral and energetic). In addition, the output of the seeded FEL is intrinsically synchronized to the HHG drive laser, thus enabling pump-probe experiments with a resolution of the order of 10 fs. The installation and successful commissioning of the sFLASH components in 2010/2011 has been followed by a planned upgrade in autumn 2011. As a result of these improvements, in spring 2012 direct HHG seeding at 38 nm has been successfully demonstrated. In this contribution, we describe the experimental layout and announce the first seeding at 38 nm.

INTRODUCTION

The SASE start-up from noise has an impact on the properties of the emitted light pulses. To name but a few, spectrum and energy of the pulses are varying on a shot-to-shot basis, and multiple uncorrelated modes lead to reduced longitudinal coherence. One way to address these issues is to operate the FEL as an amplifier for externally generated radiation fields. A promising source for the external radiation field is the laser-driven high-harmonic generation (HHG) process. The HHG pulse is longitudinally coherent with stable spectrum and energy. When correctly brought into overlap with the electron bunch in the first undulator, amplification of the HHG pulse to the GW-level can be expected. To some extent, the timing of the FEL output signal is insensitive to the arrival time jitter of the electron bunch, since it is intrinsically synchronized to the HHG drive laser. This makes the HHG-seeded FEL an ideal source for pump-probe experiments.

sFLASH is a project to study the concept of direct HHG seeding. It is installed at FLASH [1], the free-electron laser user facility in Hamburg, delivering high-brilliance SASE FEL radiation in the XUV and soft X-ray wavelength ranges. The sFLASH experiment has been installed in a 40 m long part of the FLASH beamline upstream of the FLASH SASE undulators which has been rebuilt in 2010, compare Fig. 1. Upstream of the last dipole magnet of the FLASH energy collimator, the injection chamber is installed, at which the XUV seed pulses arriving from the laser laboratory adjacent to the tunnel are sent into the electron beamline. The injection chamber is followed by a section originally installed for the ORS experiment (optical-replica synthesizer [2]). This section, which has been used for beam diagnostics, comprises two undulators in a modulator-radiator arrangement. The sFLASH longitudinal overlap setup is located at the exit of the first ORS undulator. The light pulses can be sent either to the experimental hutch outside the tunnel or to the in-tunnel diagnostic devices. This diagnostic assembly features a high-resolution XUV spectrometer and several micro-channel plates (MCPs) used to measure the pulse energy. A dedicated beamline will provide the infrastructure for detailed temporal characterization of the XUV radiation pulses. For this experiment, an NIR beamline will be commissioned to transport light from the HHG drive laser (wavelength 800 nm) to the experimental station.

sFLASH aims at sub-40 nm seeded operation without disturbing parallel FLASH SASE delivery to the already existing user stations.

EXPERIMENTAL LAYOUT

In this section we describe the layout of the hardware used in the sFLASH experiment. For the following discussion we break the setup shown in Fig. 1 down into three parts: (i) injection of the XUV seed pulses, (ii) electron beamline (where the amplification process takes place), and (iii) extraction and photon diagnostics.

Electron Beamline

As apparent in Fig.1, the sFLASH electron beamline can be subdivided in two sections: The ORS section, which we use for the longitudinal overlap of electron bunches and XUV pulses as well as to match the electron optics to the

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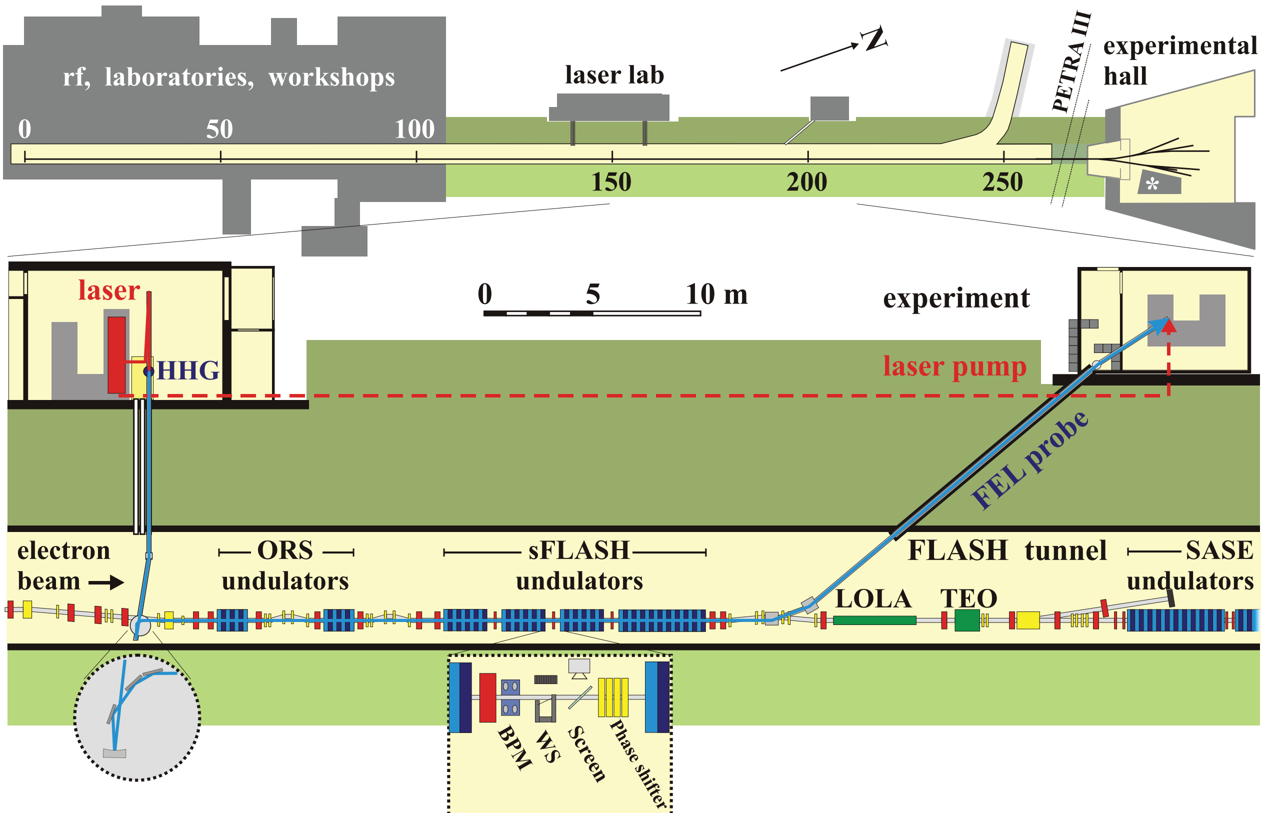

Figure 1: Schematic of the sFLASH experiment as part of the FLASH facility. FLASH (top part) has an overall tunnel length of 260 m, out of which 40 m are dedicated to the XUV seeding experiment (bottom part). Indicated components are dipole magnets (yellow), quadrupole magnets (red), undulator magnets (blue).

following sFLASH undulators. The following sFLASH undulator section comprises four variable-gap undulators.

In the ORS section two electromagnetic undulators ($N_u = 5$, $\lambda_u = 200$ mm) are installed. The first of them is tuned to a central wavelength of 800 nm. A small chicane permits extraction of the spontaneous undulator radiation together with light from the NIR drive laser. Thus, one can measure the relative arrival time of electron bunch and seed pulse.

The sFLASH undulator section consists of four variable-gap undulators. Three of them are 2 m long PETRA III type devices (U32 undulator) and the last one is a 4 m long, refurbished PETRA II device (U33 type undulator). Refer to table 1 for the main parameters.

Table 1: Parameters of the sFLASH Undulators ([3])

	U32	U33
minimum gap [mm]	9.0	9.8
period length [mm]	31.4	33
number of poles	120	240
length [m]	2	4
maximum K value	2.72	3.03

In the 0.7 m long intersection between the neighboring undulator modules a quadrupole magnet, the electromagnetic phase shifters, and a diagnostic unit are installed. An additional unit is installed at the entrance of the first undulator. These compact diagnostic units [4] accommodate both the electron and photon diagnostics needed for the transverse overlap. The electron diagnostics comprises a beam position monitor (BPM), a screen for optical transition radiation (OTR) measurements with an imaging system, and in the two units around the first sFLASH undulator wirescanners for both horizontal and vertical directions (the scintillators detecting the electron showers are mounted further downstream next to the undulators). For photon diagnostics on a shot-to-shot basis, a cerium-doped YAG (Ce:YAG) crystal converting the XUV in the HHG seed beam into visible light is available. The wire scanners, combined with a MCP as a detector for both electrons and photons, can also be used to measure the transverse profile of the XUV seed radiation. Additionally, an XUV photodiode can be moved into the beamline three meters upstream of the first undulator to determine the pulse energy of the

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arriving seed pulses.

Since the interaction between the seed pulse and the electron bunch takes place in the first undulator, extensive diagnostics have been installed around this module.

Extraction and Photon Diagnostics

Downstream of the sFLASH undulator modules, a small magnetic chicane allows the separation of the generated FEL radiation and the electrons. After extraction, the transverse properties of the generated FEL radiation can be observed by means of a movable Ce:YAG screen situated close to the extraction mirror.

In a mirror chamber further downstream the optical beamline, the FEL radiation can be deflected either into a beamline to the experimental hutch or to an in-tunnel assembly for photon diagnostics. Here, a high-resolution XUV spectrometer (McPherson 248/310G) and several MCPs are installed. The MCPs are used to determine the energy of the incoming FEL radiation pulses. Six orders of magnitude are spanned by this assembly of multiple MCPs, which is described in detail in [5, 6].

The NIR radiation required for temporal characterization of the amplified XUV pulses is transported from the laser laboratory to the experimental hutch in an evacuated optical beamline that will be commissioned in the next months.

RESULTS AND OUTLOOK

In spring 2012 direct HHG seeding at 38 nm has been successfully demonstrated. We have observed clear evidence in the energy contrast of the seeded and unseeded FEL pulses. The effect of the seeding has been reproduced and studied versus various parameters, e.g. relative timing of electron bunches and seed pulses, wavelength detuning, and transverse scans. A clear correlation between FEL pulse energy and XUV seed pulse energy has been observed within a time range of about 800 fs (FWHM) and no indication of seeding was observed outside of this time window.

According to the experience obtained with direct seeding, the stability of the longitudinal overlap is a critical issue. So far the relative arrival-time jitter of the electron bunches and the seed laser limits the fraction of the seeded bunches, introducing considerable SASE background for the statistical data analysis. Moreover, this would be a problem for future user experiments. This can be solved in the future by applying an intra-train longitudinal feedback system.

One of the next steps on the route to pump-probe experiments will be the commissioning of the NIR beamline from the laser laboratory to the experimental hutch.

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REFERENCES

[1] S. Schreiber et al.: *Status of FLASH Facility*, this conference, MOPD01

[2] G. Angelova et al.: *Observation of two-dimensional longitudinal-transverse correlations in an electron beam by laser-electron interactions*, Phys. Rev. ST Accel. Beams 11, 070702 (2008)

[3] M. Tischer et al.: *Undulators of the sFLASH experiment*, Proceedings of IPAC '10, Kyoto, Japan (WEPD014)

[4] J. Bödewadt et al.: *A compact electron photon diagnostic unit for a seeded FEL*, Proceedings of DIPAC09, Basel, Switzerland (TUBP16)

[5] F. Curbis et al.: *Photon diagnostics for the seeding experiment at FLASH*, Proceedings of FEL2009, Liverpool, UK (THOB05)

[6] F. Curbis et al.: *Characterization of seeded FEL pulses at FLASH: Status, challenges and opportunities*, Proceedings of FEL2010, Malmö, Sweden (TUPB21)

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