sFLASH: AN EXPERIMENT FOR SEEDING VUV RADIATION AT FLASH

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Abstract

A seeded free-electron laser (FEL) experiment at VUV wavelengths, known as ”sFLASH”, is being prepared at the existing SASE FEL user facility FLASH. Beyond a proof-of-principle demonstration in the VUV, the emphasis will be on high stability in terms of intensity and timing, thus providing an additional operation mode of FLASH for users. Seed pulses at wavelengths around 30 nm from high-harmonic generation (HHG) will interact with the electron beam in newly installed undulators upstream of the existing SASE undulator section. The seeded FEL radiation will be directed to a dedicated photon beamline for prototype pump-probe experiments.

INTRODUCTION

FLASH at DESY/Hamburg is a free-electron laser (FEL) based on the SASE principle, comprising a 1-GeV superconducting electron linac and a 27 m long undulator, producing pulses of sub-10 fs duration down to 6.5 nm wavelength [1, 2]. Starting up from noise, the SASE radiation consists of a number of uncorrelated modes resulting in reduced longitudinal coherence and shot-to-shot intensity fluctuations of about 18 % rms [1]. One possibility to reduce these fluctuations is to produce much longer radiation pulses with more modes contributing to the FEL output. A 3rd-harmonic rf system will be installed in 2009 to obtain 200 fs long electron bunches while retaining the present peak current [3]. An alternative approach is to operate the FEL as an amplifier of injected seed pulses from a high-harmonic generation (HHG) source. This way, not only a higher shot-to-shot stability at GW power, but a pulse duration of the order of 20 fs can be obtained. The natural synchronization between the FEL output and an external laser source will make pump-probe experiments insensitive to bunch jitter. Furthermore, the longitudinal coherence is expected to be greatly improved. An experiment recently performed at the SPring-8 Compact SASE Source [4] has demonstrated HHG seeding at 160 nm. At FLASH, an experiment (”sFLASH”) to study the feasibility of seeding at shorter wavelength (30 nm and below) is in preparation, aiming at reliable user operation at a dedicated photon beamline, while SASE pulse trains are simultaneously delivered to the present beamlines.

LAYOUT

Laser, HHG Source and Beamline

A laser laboratory adjacent to the FLASH tunnel, erected in 2007, will accommodate a Ti:sapphire system, producing ultrashort (30 fs) pulses with a pulse energy up to 50 mJ at a rate of 10 Hz, matching the rate of bunch trains in FLASH. In order to facilitate access to the HHG source, it will also be situated in the laser lab in front of a tube leading to the FLASH tunnel as sketched in Fig. 1. After passing through a differentially pumped vacuum pipe, the HHG pulses are deflected upwards by $\sim 25°$ and focused by a curved mirror. Finally, the pulses are aligned with the electron beam by a 90° deflection using three flat mirrors, resulting in a better reflectivity than with a single mirror close to the Brewster angle. The mirrors are remotely controlled to steer the HHG beam in both planes. In addition, all mirrors are mounted on translation stages in order to switch between coatings designed for two different wavelengths and – for the focusing mirror – different radii of curvature.

Undulators and Electron Beamline

The general layout of the experiment is shown in Fig. 2. Four hybrid variable-gap undulators will be installed, one 4 m long device previously used in PETRA II with a period length of 33 mm [5] as well as three new 2 m long undulators designed for the PETRA III synchrotron light

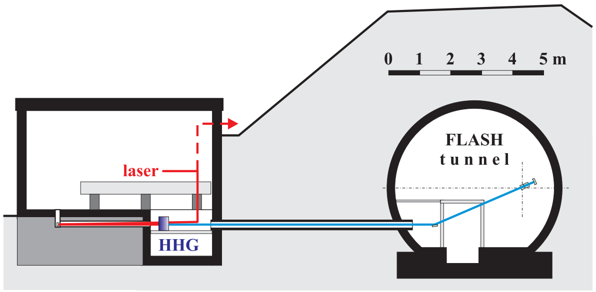

Figure 1: Cross section of the FLASH tunnel and the adjacent laser laboratory. Under the laboratory floor, the HHG source and the incident laser beam (red) are aligned with a tube, through which the HHG pulses (blue) enter the tunnel. A fraction of each laser pulse (dashed line) will be sent directly to the experiment for pump-probe applications.

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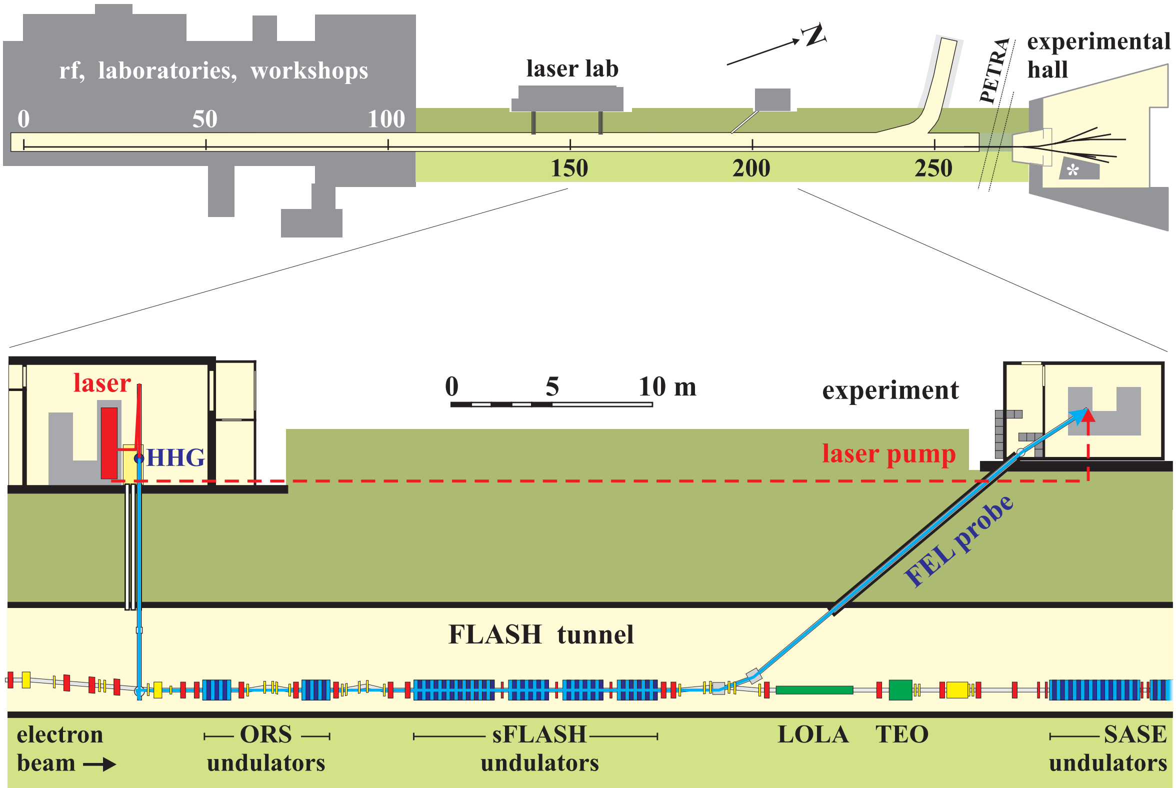

Figure 2: The FLASH facility (top) comprises a 260 m long tunnel housing the linac and undulators of a SASE FEL, followed by an experimental hall with photon beamlines. A 40 m long section (bottom) preceding the SASE undulators will be remodeled to accommodate four additional undulators for sFLASH. Seed pulses from high-harmonic generation (HHG) in a building adjacent to the FLASH tunnel will be aligned to the electron beam at a dog-leg chicane (left). At the undulator exit, the electron beam will be displaced while FEL radiation is sent by mirrors to an experimental hutch (see also Fig. 4). Delayed laser pulses will be sent directly to the hutch for pump-probe applications (dashed line). Also shown are dipole magnets and steerers (yellow), quadrupoles (red) and devices for longitudinal bunch diagnostics (ORS[7, 8], LOLA[9] and TEO[10]).

source with a period length of 31.4 mm [6]. Since there is only one dog-leg chicane allowing for backtangent entry of radiation pulses, the sFLASH undulator section will be preceded by two already existing electromagnetic undulators used for the optical-replica synthesizer (ORS), in which the electron bunches interact with 800 nm laser pulses for diagnostics purposes [7, 8]. The undulator section for sFLASH is shown in more detail in Fig. 3. Between the undulators, 0.7 m long intersections accommodate a quadrupole magnet, a phase shifter, and diagnostic devices such as beam position monitors. A phase shifter is a set of dipole magnets forming a small chicane in order to compensate the shift of the ponderomotive phase in the drift space between the undulators. At either end of the first undulator, a diagnostics block is installed to determine and align the transverse position of electrons and HHG pulses. It comprises a wire scanner with a micro-channel plate to detect emitted or scattered photons, another screen to produce optical transition radiation (OTR), and a Ce:YAG fluorescence screen. Within the undulators, extruded aluminum chambers with a vertical aperture of 9 mm and machined down to a wall thickness of 0.5 mm will be employed in order to maximize the range of wavelengths to which the undulators can be tuned. These chambers are similar to those designed for the European XFEL [11]. The quadrupole positions and the resulting beta functions in this region, shown in Fig. 5, were optimized using the code *elegant* [12] such that electrons passing the collimator of the upstream dog-leg section will not hit the chamber walls, thus protecting the undulator magnets against excessive radiation.

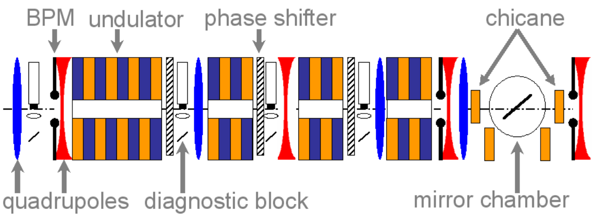

Figure 3: Schematic layout of the sFLASH undulator section with diagnostics, phase shifters and quadrupole magnets between the undulators and a magnetic chicane further downstream to extract the FEL radiation by a mirror.

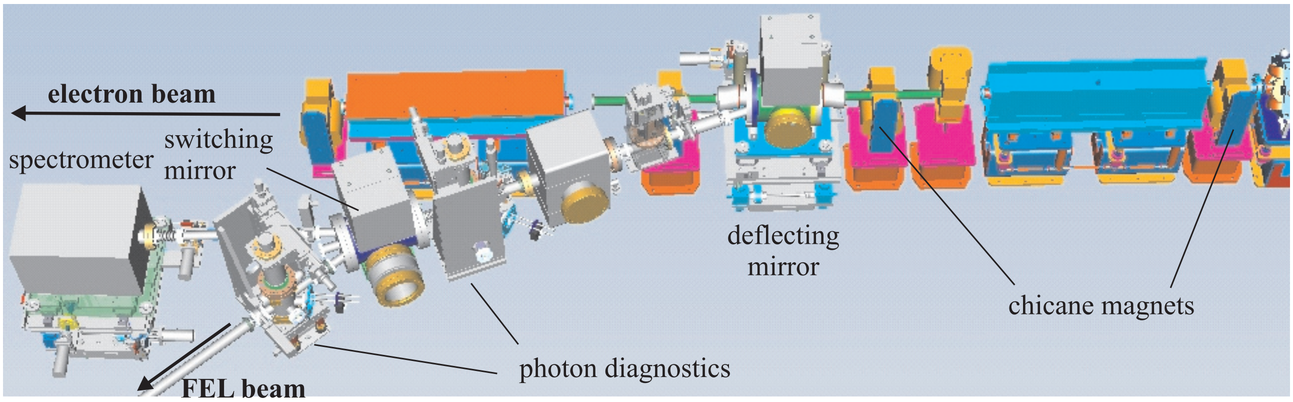

Figure 4: Extraction of the seeded-FEL radiation by a deflecting mirror pair while the electron beam (from right to left) is vertically displaced by a four-magnet chicane. The switching mirror pair directs the photon beam either to the spectrometer or to the experimental hutch outside the FLASH tunnel. The photon beam can be steered horizontally by the deflecting mirrors and in both planes by the switching mirrors by tilting the respective mirror chamber and observing the beam position at two diagnostics stations.

Photon Beamline and Experiment

At the exit of the undulator section, a magnetic chicane will displace the electron beam vertically, while the FEL pulses are extracted. Two pairs of plane amorphous carbon coated Si mirrors with grazing incidence at 5° will direct the pulses into a spectrometer[1] located in the FLASH tunnel, as shown in Fig. 4. The reflectivity of the mirrors at this angle is typically better than 85%. In the spectrometer, a 40 mm wide micro-channel plate with a CCD can be scanned along a Rowland circle, and data are read out by a fiber taper. Spectra can be recorded on a single-shot basis with a large dynamic range at wavelengths from 1 nm to 35 nm (at the detector center) with a resolution of $\lambda/\Delta\lambda \approx 1000$. Alternatively to directing the FEL pulses into the spectrometer, they can be sent to an experimental hutch outside the tunnel by switching the second mirror pair. Here, pump-probe experiments with a time resolution of the order of 30 fs can be performed by combining the seeded-FEL pulses with the naturally synchronized laser pulses.

CHALLENGES

Mechanical Design and Installation

The mechanical design of mirror chambers, two for the HHG beamline, two for the FEL photon beamline is very demanding due to the many degrees of freedom, in which the mirrors have to be remotely controlled. Since windows are not permissible, differential pumping is required and great care must be taken to avoid any risk of contaminating the accelerator vacuum.

Squeezing the additional undulators together with magnets, diagnostics and experimental devices such as the ORS [7, 8] and the transversely deflecting cavity LOLA [9] into the available space and providing adequate beta functions (Fig. 5) is yet another challenge.

Furthermore, the variable-gap undulators were designed for the PETRA storage ring and transporting them through the FLASH tunnel to their intended position is difficult and requires special tools constructed for this purpose.

Seed Power

FEL simulations [13] using the code GENESIS [14] suggest that a HHG pulse energy of 1 nJ (peak power 50 kW) is sufficient to seed the FEL and reach saturation at wavelengths of 30 nm and below within the undulator length of 10 m. A recent compilation [15] reports that the generation of HHG pulses above 1 nJ has been demonstrated down to $\sim$ 15 nm. For these wavelengths, design compromises (e.g. using only one focusing element) must be made to minimize losses on the way to the FEL undulator. The tolerances regarding seed power and transverse displacement of HHG radiation with respect to the electron beam have been investigated in [16].

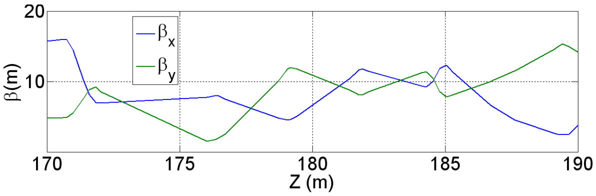

Figure 5: Horizontal (x) and vertical (y) beta function in the vicinity of the sFLASH undulators. The z-coordinate corresponds to the meter scale shown in Fig. 2.

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[1] McPherson 248/310G; 1 m focal length; entrance slit adjustable from 5 μm to 500 μm in front of a gold-coated grating with 1200 grooves/mm, blazed at 20 nm and 3° angle of incidence.

Six-dimensional Radiation-electron Overlap

The transverse overlap between electron bunches and HHG pulses will be achieved by measuring their respective position at either end of the first sFLASH undulator, where the challenge lies in detecting the weak and short-wavelength HHG pulses. Next, the variable-gap undulators must be spectrally matched to the HHG pulses using the spectrometer. For the temporal overlap between HHG pulses and electron bunches of about 200 fs duration, the relative jitter should not exceed 40 fs rms, which can be achieved using an intra-pulse train feedback system [17] with a fast bunch-arrival monitor and adjusting the gradient of the accelerating modules upstream of the first bunch compressor accordingly. The HHG pulses will be locked to the synchronization system using a two-color balanced optical cross correlator currently being developed [18]. Finally, the timing between HHG pulses and undulator radiation will be prealigned using a streak camera [19] and then varied until FEL gain occurs.

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REFERENCES

[1] W. Ackermann et. al. Nature Photonics 1 (2007), 336.
[2] K. Honkavaara, B. Faatz, S. Schreiber, this conference.
[3] K. Flöttmann et al., TESLA report TESLA-FEL-2001-06.
[4] G. Lambert et al., Nature Physics 4 (2008), 296.
[5] K. Balewski et al., Proc. HEACC’95, Dallas, 275.
[6] M. Tischer et al., Proc. SRI’06, Daegu, 343.
[7] E. Saldin, E. Schneidmiller, M. Yurkov, Nucl. Inst. Methods A 539 (2005), 499.
[8] J. Bödewadt et al., this conference (THBAU04).
[9] M. Röhrs, C. Gerth, H. Schlarb, Proc. PAC’07, Albuquerque, 104.
[10] A. Azima et al., Proc. EPAC’06, Edinburgh, 1049.
[11] M. Altarelli et al. (Eds.), The European X-ray Free Electron Laser, Technical Design Report, DESY 2006-097.
[12] M. Borland, ”elegant: a flexible SDDS-compliant code for accelerator simulation”, Advanced Photon Source LS-287 (2000).
[13] A. Azima et al., EPAC’08, Genova, 127.
[14] S. Reiche, Nucl. Inst. Methods A 429 (1999), 243.
[15] B.W.J. McNeil et al., New Journal of Physics 9 (2007), 82.
[16] V. Miltchev et al., this conference.
[17] F. Löhl et al., Proc. EPAC’06, Edinburgh, 2781.
[18] S. Schulz et al., Proc. EPAC’08, Genova, 3366.
[19] R. Tarkeshian et al., this conference.