STATUS OF sFLASH, THE SEEDING EXPERIMENT AT FLASH [*]

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Abstract

Recently, the Free electron LASer in Hamburg (FLASH) at DESY has been upgraded considerably [1]. Besides increasing the maximum energy to about 1.2 GeV and installation of a third-harmonic rf cavity linearizing the longitudinal phase space distribution of the electron bunch, an FEL seeding experiment at wavelengths of about 35 nm has been installed. The goal is to establish direct FEL seeding employing coherent VUV pulses produced from a powerful drive laser by high-harmonic generation (HHG) in a gas cell. The project, called sFLASH, includes generation of the required HHG pulses, transporting them to the undulator entrance of a newly installed FEL amplifier, controlling spatial, temporal and energy overlap with the electron bunches and setting up a pump-probe pilot experiment. Sophisticated diagnostics is installed to characterize both HHG and seeded FEL pulses, both in time and frequency domain. Compared to SASE-FEL pulses, almost perfect longitudinal coherence and improved synchronization possibilities for the user experiments are expected. In this paper the status of the experiment is presented.

INTRODUCTION

FLASH is a free-electron laser based on the SASE principle, comprising a 1.2 GeV superconducting electron linac and a 27 m long undulator, producing EUV pulses of sub-10 fs duration [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 [2]. One possibility to reduce these fluctuations is to operate the FEL as an amplifier of injected seed pulses from a high-harmonic generation (HHG) source. In this way, high shot-to-shot stability at GW power and pulse duration of the order of 20 fs can be expected. The natural synchronization between the FEL output and an external laser source will make pump-probe experiments insensitive to inevitable bunch jitter. Furthermore, the longitudinal coherence is expected to be greatly improved. sFLASH is an experiment to study the feasibility of seeding at short wavelengths (38 nm and below). sFLASH eventually aims at reliable seeding operation for a dedicated photon beamline, while SASE pulse trains are simultaneously delivered to the present beamlines [3].

HHG SOURCE

The concept of a high-harmonic-generation seed pulse source employed at sFLASH was presented in [4]. In the following the realization is reported. The source has been installed successfully at the entrance of the incoupling beamline. Following alignment of the harmonics to the first diagnostics in the linear accelerator area, spectra of the HHG frequency comb of Argon source were recorded. Figure 1 shows the result of such a measurement.

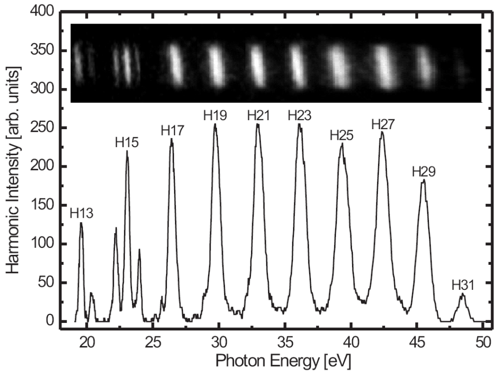

Figure 1: The high harmonics spectrum of the sFLASH seed Argon source. The 21st harmonic will be used as the seed for sFLASH.

TRANSPORT OF HHG

In order to transport and focus the XUV radiation of the HHG source into the sFLASH undulator a dedicated 12 m long beamline is installed at the end of the energy collimator section of the linac. Using dipole magnets of the linac, a closed orbit bump can be generated which gives the possibility to couple photons to e-beam reference orbit. One UHV mirror chamber steers the beam to the level of the e-beam using a grazing incidence at 13.9°. Another mirror chamber contains multilayer normal incidence spherical mirror to focus the HHG beam and a mirror triplet, with 14.1° grazing incidence at each mirror, finally deflects the beam onto the undulator axis. The grazing incidence mirror substrates are coated with B_4C for wavelengths around 35 nm and with Mo for 13 nm. The exchange of these mirrors are remotely controlled. HHG focusing can be done by six different mirrors (see Fig. 2). This gives options for two different wavelengths (Si/Sc and Mo/Si multilayer coating)

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and three different focal lengths (f1 = 6.25 m; f2 = 7 m; f3 = 8.5 m). The alignment of the XUV beam within the undulator will be done by changing the transverse position of the focal mirror and by tilting the first grazing incidence mirror. From simulations the overall transmission of the beam line, taking all polarization effects into account, is about 8% at 38 nm.

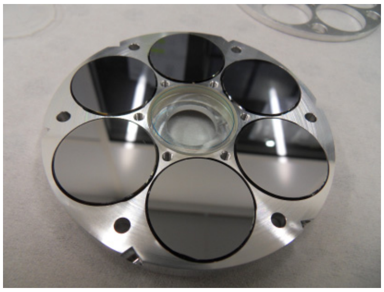

Figure 2: 6-fold focal mirror wheel.

OVERLAP OF ELECTRON BEAM AND HHG SEED

Transverse Overlap

In order to control and optimize the overlap of photon- and electron beams, diagnostics blocks are installed upstream of each undulator [5]. By means of these diagnostics, the transversal beam profile and position can be monitored. The first diagnostics unit is placed in front of the first mirror chamber. Here a quadrant XUV photodiode will give the possibility to measure the beam position. A Ce:YAG crystal together with dedicated optics and a EMCCD camera are used to image the beam profile. Along the electron beamline Ce:YAG crystals are installed in six more screen stations. Two of these stations, in front and after the first undulator module, are permanently equipped with highly sensitive EMCCD cameras.

Temporal Overlap

To enable a longitudinal overlap, the HHG drive laser will be synchronized with the laser master oscillator of FLASH by an optical synchronization system. A dedicated setup to monitor the temporal overlap is being installed and under commissioning [6].

sFLASH UNDULATORS

sFLASH comprises a 10 m long variable gap undulator section. Three 2 m long U32 undulators are followed by a 4 m long U33 undulator [7]. Magnetic tuning shows promising results that meet sFLASH specifications. The undulator vacuum chamber uses the achievements of XFEL [7].

SEPARATION OF SEEDED RADIATION FROM ELECTRON BEAM

After the undulators section, a vertical magnetic chicane will make a closed-orbit bump and the FEL radiation is extracted. After that the photon beam passes through the first diagnostics block where a paddle with irises and a Ce:YAG screen will be used for the alignment. Here there is also a port to couple in an alignment laser. Then the radiation can be switched between two branches by means of two pairs of mirrors. The branch inside the tunnel includes an intensity monitor and an XUV spectrometer. The other possibility is to send the radiation into the experimental hutch outside the tunnel where it is possible to perform time-resolved pump-probe studies with high temporal resolution. The layout of the photon beamline is shown in Fig. 3. The mirrors are plane amorphous carbon coated silicon substrates with a reflectivity around 90% at grazing incidence. A portion of the mirros has larger roughness resulting in the attenuation on the detectors of the beam close to saturation.

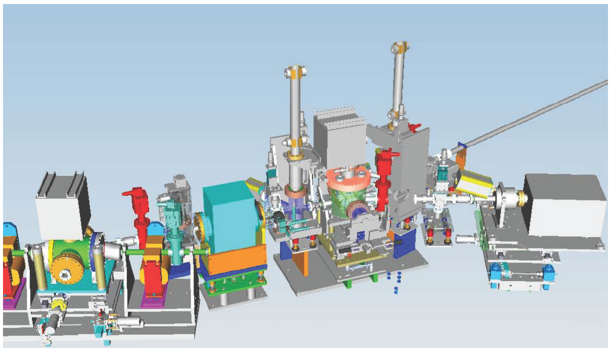

Figure 3: Layout of the photon beamline. The FEL radiation comes from left, it is deflected by the first mirror, then passes through the diagnostics unit. A further mirror allows to send the beam either to the XUV spectrometer or to the experimental hutch.

SEEDED FEL DIAGNOSTICS

An XUV spectrometer [8] installed in the FLASH tunnel will measure spectra on a shot-to-shot basis in the wavelength range between 5 and 38 nm with a resolution of $\lambda/\Delta\lambda$=1000. Using the spectrometer, the spontaneous emission from the undulators will be tuned in order to match the seed laser wavelength. Furthermore, to characterize the gain curve of the seeding process a detector is developed which is able to span over a large range of intensity i.e. from the spontaneous undulator radiation to the seeded FEL in saturation. The intensity monitor is based on the detection of scattered radiation from a metal mesh using microchannel plates (MCPs). The MCP voltage can be changed and this gives a dynamical range of four orders of magnitude in photon flux. The missing two-three orders of magnitude can be overcome placing three MCPs in different positions with respect to the mesh. Simulations show the different efficiencies for each MCP in a certain geometry. Since the efficiency depends also on the mesh which is used, two different meshes (open area 65% and 44%) are mounted on a translation stage that allows to select them depending on the photon flux. The readout of the MCP signal consists of a preamplifier followed by a stretcher, that lengthens the short signal (usually about 1 ns). The output of the stretcher is send to an ADC which is read by the DAQ. During the calibration of this detector (performed at FLASH–BL1 last year) the amplification curve of sFLASH was simulated by attenuating the SASE beam from the μJ range down to the pJ range. For this purpose a combination of the gas attenuator [9] and aluminum filters with different thicknesses were used. The last measurement has been carried out detuning SASE to have only spontaneous emission from the undulator which is similar to the starting point of the commissioning phase in the sFLASH project. The wavelength used was 13.7 nm. The MCP output signal has been measured for different high-voltage settings and the shot-to-shot energy of the pulses measured by the gas monitor detector [9] has been recorded. Combining all the measurements with different attenuation of the beam and different voltage settings, it is possible to retrieve the required dynamical range with this detector. In Fig. 4 it is shown that this range is 6-7 orders of magnitude wide.

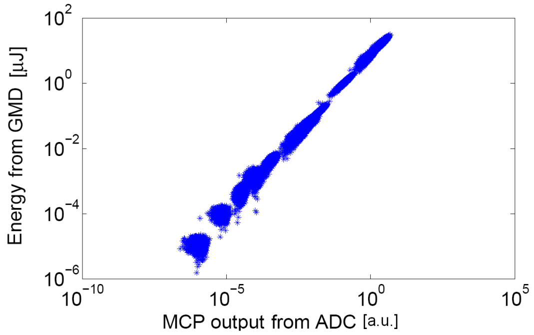

Figure 4: Cross-calibration of the intensity monitor with energy measurements from the gas monitor detector for different voltage settings.

Simulations for Seeding at 38 nm

The considered FEL parameters are summarized in Table 1. The properties of the FEL output, is simulated with the 3-D time dependent code GENESIS [10]. As presented in Fig. 5, the saturation length for the seeded part of the bunch is expected to be about 8 m, which is in good agreement with the value predicted by the Xie formula [11]. Of great importance is also to assure a good contrast between the amplified pulse and the SASE radiation. Figure 6 shows a logarithmic plot of the radiation power at saturation as a function of the local distance in the bunch. The amplified seed (around s = 40 μm) exceeds the SASE power by about three orders of magnitude. The signal-to-noise ratio $E_{seed}/E_{SASE} \approx 90$, where $E_{seed} \approx 70\,\mu$J is the energy in the seeded part of the bunch and $E_{SASE} \approx 0.8\,\mu$J is the total energy in the SASE pulse.

Table 1: Electron Beam and Seed Parameters

Energy, E_0	750 MeV
Peak current, I_0	1500 A
rms bunch length, σ_z	80 μm
rms energy spread	0.2 MeV
Normalized rms emittance, ϵ_n	2 mm mrad
seed pulse duration, FWHM	20 fs
wavelength, λ_r	38 nm
energy in the harmonic	1.0 nJ

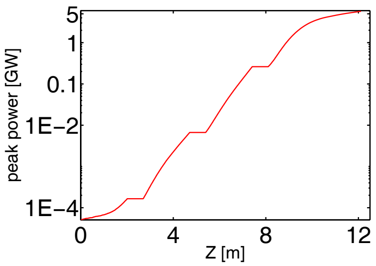

Figure 5: Radiation power at $\lambda_r = 38$ nm in the seeded part of the bunch along the sFLASH undulator.

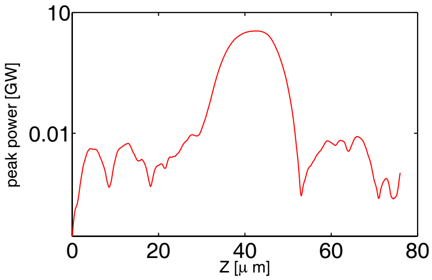

Figure 6: Radiation power at the onset of the nonlinear regime at Z=10 m (see Fig. 5) as a function of the local coordinate *s* in the bunch.

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