CHARACTERIZATION OF SEEDED FEL PULSES AT FLASH: STATUS, CHALLENGES AND OPPORTUNITIES*

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Abstract

Since 2004 the free-electron laser FLASH at DESY has been operated in the Self-Amplified Stimulated Emission mode (SASE), delivering gigawatt pulses with wavelengths between 6.5 nm and 40 nm in the femtosecond domain. In 2009 DESY installed an additional radiofrequency module for controlling the phase space of the electron bunches that gives the possibility to generate bunches with high peak currents but ten times larger pulse durations (≈200 fs). The relaxed timing requirements of the new configuration allows to externally seed FLASH with high-order harmonics of an optical laser below 40 nm generated in a gas target (sFLASH). Because in this case the amplification is triggered within the seed pulse length instead of starting from the shot-noise (as in the SASE process), spikes in temporal/spectral pulse profiles should be absent and the temporal jitter should be eliminated. In this contribution we present the current status of the sFLASH photon diagnostics including first commissioning results.

SEEDING FLASH WITH HIGH HARMONICS

The SASE regime has been explored at FLASH for several years [1] but due to startup from noise the radiation consists of a number of uncorrelated modes resulting in a poor longitudinal coherence and shot-to-shot fluctuations of the output pulse energy. In order to improve the longitudinal coherence, the electron beam can be seeded with high-order harmonics of an optical laser [3]. The sFLASH experiment aims to demonstrate direct seeding below 40 nm and to use the radiation for pump-probe experiments with fs synchronization in a dedicated beam line.

The FLASH facility has been upgraded during the last shutdown with the installation of an additional accelerating module and a third harmonic cavity [2]. This new device allows to linearize the phase space and produce 200 fs long electron bunches with few kA of peak current. Only with longer electron bunches it is possible to overcome the jitter and synchronize an external seed with the electrons. The new layout of the FLASH facility after the 2009-2010 shutdown is shown in Fig. 1.

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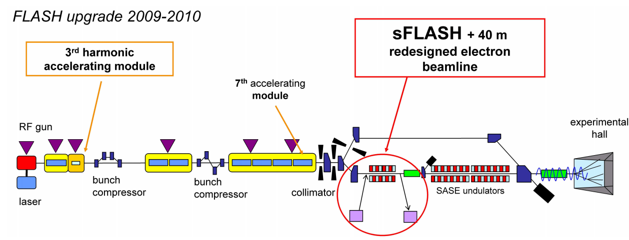

Figure 1: New layout of FLASH after the shutdown: a third harmonic cavity is installed before the first bunch compressor and the section between the collimator and the SASE undulators accommodates the components for the seeding experiment.

sFLASH Setup

The high-order harmonics are generated in a gas target outside the FLASH tunnel and by means of multilayer mirrors the seed is transported into the tunnel and coupled into the electron beam pipe. In order to reach saturation within the 10 m long undulators, the HHG pulses must be of the order of nJ when focused into the electron beam. The drive laser of the HHG source is locked to the electron beam using an optical cross correlator [5] with a relative jitter less then 50 fs rms. A 40 m long section of FLASH has been completely remodeled to accommodate the 10 m variable-gap undulators for the sFLASH experiment, which are three new 2 m-long undulators (PETRAIII type, 31.4 mm period) and an old 4 m-long undulator (period 33 mm) previously used at PETRAII synchrotron light source. The vacuum chamber within the undulators has been design in order to maximize the range of achievable wavelengths [9]. Each intersection between undulators will include a quadrupole, a phase shifter and beam-position monitors. A further diagnostic apparatus is foreseen to help looking for the transverse overlap. Placed at the end of each undulator, the diagnostic blocks include a wire scanner with MCP (Micro Channel Plate) detector, an OTR screen and a Ce:YAG fluorescent screen. The transverse overlap between the seed laser and the electron beam is obtained looking at screen before and after the first undulator where the overlap should take place. The "coarse" temporal overlap between the drive infrared laser and the synchrotron radiation produced by a short undulator installed before the sFLASH undulators is measured first using a photomultiplier and with a streak camera [6].

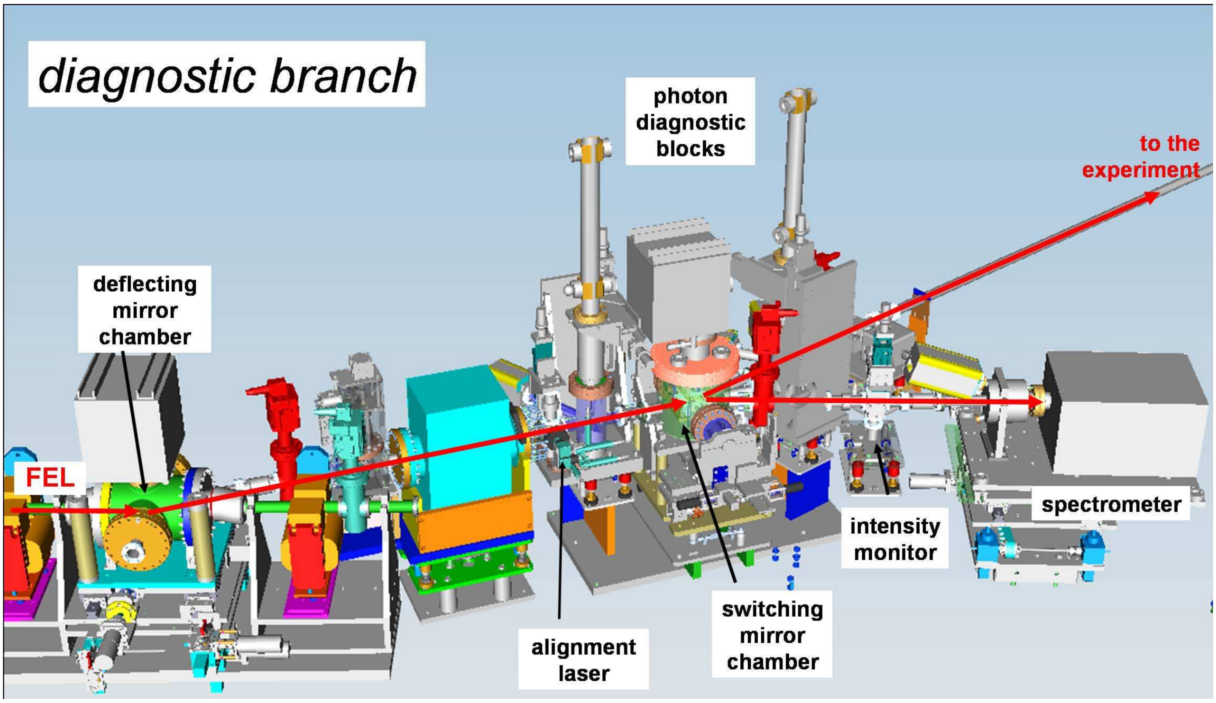

Figure 2: Layout of the photon beam line inside the FLASH tunnel. While the electron beam pass through a magnetic chicane the FEL radiation is deflected by the first three mirrors, then passes through the first diagnostic unit with YAG screen and different apertures. After that a further couple of mirror allows to send the photon beam either to the XUV-spectrometer or to the experimental hutch outside the tunnel.

PHOTON DIAGNOSTICS

The sFLASH experiment has its own photon beam line with dedicated diagnostics inside the accelerator tunnel. The technical drawing of the photon beam line is shown in Fig. 2. After the undulator section, the electron beam is vertically displaced by a magnetic chicane and the FEL radiation is deflected by means of three mirrors. The mirrors are plane silicon substrates coated with amorphous carbon with grazing incidence at 3.3°. The resulting deflection is 10° with respect to the nominal electron beam orbit. The reflectivity at this angle is typically between 85 and 90%. A small portion of the mirrors (2.5 mm) has a chromium coating in order to deflect the radiation around 4.4 nm which will result from the harmonics of the seeded FEL radiation. A micromap measurement has been performed at BESSY in order to estimate the roughness of the mirrors and it results in 0.5 nm FWHM. Considering the reflectivity and the penetration in material and assuming measured values [7] one can say that the expected radiation on the mirrors is one order of magnitude below the radiation damage threshold. The three mirrors are placed in a mirror chamber that can be moved in horizontal, vertical and angular direction with respect to the beam path. The photon beam line continues with the mirror of the alignment laser which can be inserted in order to check the alignment of the further components. Then there is the first diagnostic block which is equipped with a paddle with different apertures (diameter from 4 to 0.25 mm) and a Ce:YAG screen. Two CCD-cameras placed at different angles can be used to look at the paddle which can be moved in both transverse directions in order to follow the spot of the radiation. After that a second mirror chamber allows to send the radiation either into the diagnostic branch (that includes intensity monitor and XUV-spectrometer) or into the experimental hutch outside the tunnel where time-resolved pump-probe studies can be performed with high temporal resolution. The switching unit consists of two pairs of plane carbon coated mirrors (also with a small portion with chromium coating). One half of the mirrors guiding the radiation to the diagnostic branch has larger roughness resulting in the attenuation of the FEL by diffuse scattering. A reduction of two orders of magnitude in photon flux is expected on the detectors. With this mirror chamber one can adjust the height of the photon beam on both branches. All the components have been referenced with a laser tracker and a theodolite before the installation in the tunnel. Besides all the movable parts have an absolute measurement of displacement for each degree of freedom.

Spectrometer

In order to match the undulator-HHG wavelength and to observe the seeded FEL radiation an XUV-spectrometer capable to measure spectra on a single-shot basis with large dynamical range is installed in the FLASH tunnel. This instrument [10] has 1 m focal length, a gold-coated grating (blazed at 20nm) and 3° angle of incidence. The detector consists of a 40 mm MCP mounted perpendicular to the exit beam of the instrument tangent to the Rowland circle and a fiber taper is connected to the CCD for data readout. The MCP+CCD ensemble can be moved along the Rowland circle to scan any wavelength between 1.7 nm and 39 nm. The resolution of the system at 13 nm and 30 nm is about $\lambda/\Delta\lambda$=1000. The spectrometer has been tested with a plasma source before the installation in the tunnel and resolution, wavelength range and triggered operation have been checked extensively (see Fig. 3).

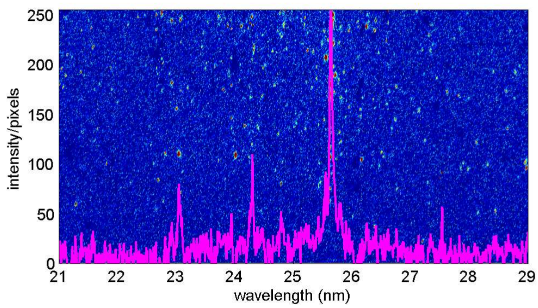

Figure 3: Spectrum of the plasma source.

The spectrometer is mounted on a table that can be moved remotely in vertical, horizontal and angular direction. In orders to adjust the spectrometer position, there is a CCD-camera looking at the slits and the alignment can be performed using either the alignment laser or the infrared drive laser.

Intensity Monitor

The intensity monitor is a detector able to span over a large range of intensity from the spontaneous undulator radiation to the seeded FEL in saturation (i.e., six-seven orders of magnitude in photon flux). We adopted a concept already tested at FLASH [11]: a metal mesh scatters the incoming photons and the diffused radiation is detected by MCPs. The best reflectivity in the wavelengths range between 13 and 30 nm is shown by gold and two different meshes (open area 65% and 44%) are mounted on a translation stage that allows to select the most suitable one depending on the photon flux.

In order to adjust the amplification of the detected signal, the MCP voltage is set accordingly but this gives a dynamic range of only four orders of magnitude. To overcome this problems different geometries were tested performing simulations with the code ZEMAX [12] taking into account tabulated values for the reflectivity of gold at 30 nm [13]. The gold mesh is placed at the center of the detector at 45° with respect to the FEL beam. Three MCPs are used: one is at 45° with respect to the mesh (90° with respect to the FEL beam), the other two MCPs have a hole in the middle to be place on axis with respect to the FEL beam. The first holed MCP detects the radiation scattered backward from the mesh and the second holed one detects the radiation scattered forward.

Due to the geometry, the detection efficiency of each MCP is different at the same photon energy, hence increasing the dynamical range of detection. Simulation show that by changing the distance from the mesh for each MCP it is possible to change the detection efficiency. Experimentally it is possible to find an overlap in the detection region for certain voltage settings of the MCPs. Once the overlap is found it is possible to switch from one MCP to the other to follow the gain curve. It has been measured [14] that the dynamical range of this detector is 6-7 orders of magnitude.

Dedicated electronics for data acquisition has been developed at DESY. The readout of the MCP signal consists of a preamplifier followed by a stretcher, that lengthen the short signal (usually about 1 ns). The output of the stretcher is sent to an ADC which is read by the DAQ.

FIRST COMMISSIONING RESULTS

In this section the results from the last two weeks of shifts will be presented. The analysis of data is still on going.

The commissioning of the diagnostics branch started at the end of the shutdown with the alignment of the mirror chambers, first with the alignment laser and then with the infrared drive laser. After that it has been possible to characterize the HHG source with the spectrometer and the intensity monitor. The harmonics of the seed laser have been detected (see Fig. 4) in different configurations of the focusing mirror in the injection beam line.

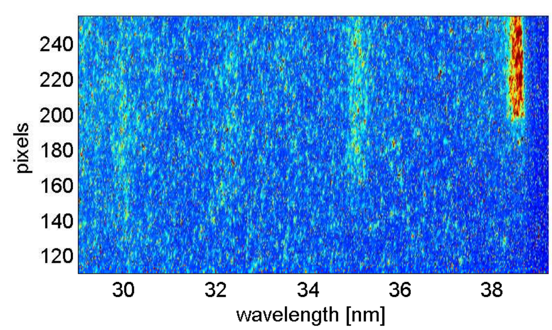

Figure 4: Spectrum of the HHG source as recorded by the spectrometer in the diagnostic branch. Exposure 10 s, slits 500 μm.

The spontaneous radiation from each undulator has been measured during the first shifts with the electron beam and different gap values have been found for different electron beam energies. An example is shown in Fig. 5.

After tuning the gap of all undulators to the same wavelength, we observed SASE radiation on the first YAG screen in the photon beam line (see Fig. 6) and the spectrum has been also measured with the spectrometer at the end of the diagnostic branch (see Fig. 7).

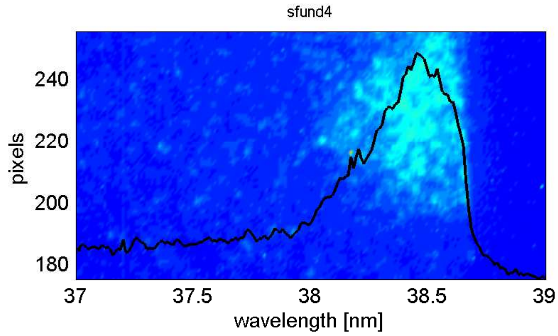

Figure 5: Spectrum of the spontaneous radiation from the last sFLASH undulator. Exposure 1 s, slits 500 μm.

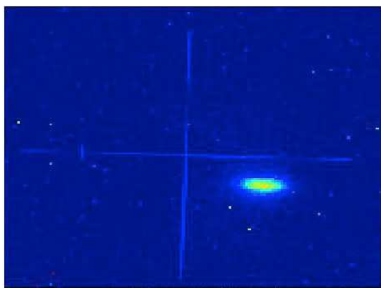

Figure 6: SASE radiation on the YAG screen in the first diagnostic block. The distance between the center and the first marker is 5 mm.

The preparatory phase included also the commissioning of the intensity monitor with a deuterium lamp which will give a further estimation of the relative gain of each MCP with respect to the applied voltage. Once the temporal overlap will be established the photon diagnostics will allow the observation of the spectral narrowing on the spectrometer and the measurement of the gain curve by means of the intensity monitor.

A further step for the experiment would be testing the parasitic operation during the normal FLASH SASE operation: this will result in a extended time to test and to improve the source.

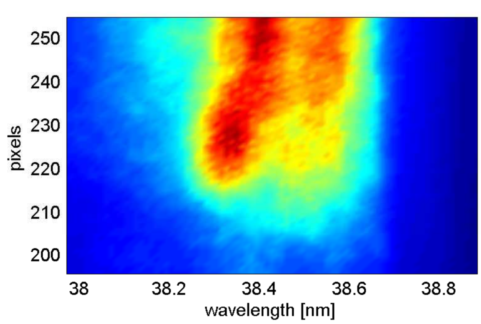

Figure 7: SASE single shot spectrum as recorded by the spectrometer with 100 μm slits.

CONCLUSIONS

The commissioning phase of the sFLASH project has started and all the components have been tested during the past months. The diagnostics tools showed good performances and will be able to detect the seeded FEL pulses. The upgrade of the FLASH facility can profit from the experience gained with the sFLASH project in seeding an FEL with an HHG source below 40 nm. The results in terms of stability and spectral coherence will drive in general the design of future FELs for user operation.

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REFERENCES

[1] W. Ackermann et al., Nature Photonics 1, 336 - 342 (2007)

[2] S. Schreiber et al., "FLASH upgrade and first results", these proceedings, TUOBI2

[3] G. Lambert et al., Nature Physics 4, 296 - 300 (2008)

[4] V. Miltchev et al., "Technical design of the XUV seeding experiment at FLASH", Proc. FEL09, Liverpool

[5] S. Schulz et al., Proc.EPAC08, Genova

[6] R. Tarkeshian et al., "Femtosecond temporal overlap of injected electron beam and EUV pulse at sFLASH", Proceedings IPAC10, Kyoto

[7] Hau-Riege et al., APL 90, 173128 (2007) and H. Wabnitz et al., in preparation

[8] F. Loehl et al., Proc. EPAC08, Genova, 3360; F. Loehl et al., Proc. EPAC06, Edinburgh, 2781

[9] M, Altarelli et al., "The European X-ray Free Electron Laser", Technical Design report, DESY 2006-097

[10] McPherson 248/310G; `http://www.mcphersoninc.com`

[11] L. Bittner et al., "MCP-based photon detector with extended wavelength range for FLASH", Proc. FEL07, Novosibirsk, 334

[12] `http://www.zemax.com`

[13] LBL database: `http://henke.lbl.gov/`

[14] F. Curbis et al., "Photon diagnostics for the seeding experiment at FLASH", Proc. FEL09, Liverpool