FLASH STATUS AND UPGRADE

B. Faatz*, J. Feldhaus, K. Honkavaara, J. Rossbach, S. Schreiber and R. Treusch
for the FLASH team,
Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

Abstract

The free-electron laser user facility FLASH at DESY, Germany is world-wide the only SASE-FEL operating in the VUV and the soft X-ray wavelengths range. Since summer 2005, FLASH operates as a user facility providing almost fully coherent, 10 femtosecond long laser radiation in the wavelength range from 47 nm to 6.5 nm with an unprecedented brilliance - many orders of magnitude higher than conventional facilities. The SASE radiation contains also higher harmonics. Several experiments have successfully used the third and fifth harmonics, in the latter case down to a wavelength of 1.59 nm. Starting autumn 2009, FLASH will be upgraded with an additional superconducting TESLA type accelerating module boosting its beam energy to 1.2 GeV. This will allow lasing below 5 nm. In addition, a 3rd harmonic accelerating module will be installed, which improves the longitudinal phase space and the overall performance of the facility.

INTRODUCTION

FLASH, The free-electron laser in Hamburg, has been in operation as user facility since summer 2005 [1]. Initially, the minimum achievable wavelength was approximately 13 nm at an electron beam energy of 700 MeV. Since the upgrade in 2007, the energy has been increased to 1 GeV, thus decreasing the wavelength [2]. The wavelength produced has ranged from 6.5 to 60 nm with pulse trains of up to 800 at 1 MHz with a 5 Hz repetition rate. For users, wavelengths from 6.8 to 47 nm with pulse trains from 50 kHz to 1 MHz, from single bunch to 140 pulses with 200 ms (5 Hz) intervals have been produced. The duration of user periods is about 3 to 4 weeks. The periods between, needed for exchange of user experiments and commissioning of the beam lines for those experiments, are used to improve the facility and allow for general accelerator studies. Also education of operators takes place during these periods. During a user period, the demands on radiation properties usually differ from experiment to experiment. This ranges from difference in wavelength to intra-bunch spacing and number of bunches. However, also more delicate properties such as spectral purity and radiation pulse length are parameters that need to be adjusted. In this paper, we will discuss the present layout of the FLASH facility and its performance. The upgrade in 2009/2010 will be outlined. Finally, an outlook for the long term future will be given.

* bart.faatz@desy.de

LAYOUT OF THE FACILITY

FLASH is an FEL which uses superconducting accelerating modules of the TESLA type (see Figure 1). Electrons are generated by a normal conducting L-band RF-gun. The total number of bunches is up to 800 per RF-pulse for a 1 μs spacing at a repetition rate of 5 Hz. The bunches are accelerated up to a final energy of 1 GeV by six accelerating modules. Behind the first and third modules, the bunches are compressed at nominal energies of about 130 and 450 MeV, respectively. At its final energy, the electron beam is collimated transversely and in energy by a dogleg, after which the FEL radiation is generated in a fixed-gap undulator consisting of 6 undulator segments of 4.5 m length each. Before dumping the electron beam, there is a possibility to generate THz radiation in an infrared, electromagnetic undulator, which can be used for automatically synchronized radiation for pump probe experiments. Before the radiation is directed to any of the five experimental stations, it is characterized in position and intensity by several gas monitor detectors and its wavelength can be determined by moving in a mirror into a special spectrometer branch.

Details about photon diagnostics and user stations can be found in [3]. Here we just mention that there are in total five experimental stations, two of them behind a monochromator, three with different focusing mirrors in front. In order to supply as many user as possible with beam time, two experiments are built in a row where possible within spatial and experimental limitations.

PERFORMANCE

The photon wavelengths which have been produced range from 6.5 to 60 nm. To users, a more limited range between 6.8 and 47 nm has been delivered as given in Table 1. The pulse energy has been gradually increased to the present level of 20 to 50 μJ, depending on wavelength and additional user requirements, such as spectral purity. For those users that need average brilliance, up to 500 bunches per second have been produced (100 per RF pulse). Longer pulse trains are possible and have been produced during dedicated study times.

In Table 2, the SASE level averaged over a user block is given for the second user period from November 2007 to August 2009. Typical values of the SASE level shown here depend on the wavelength, the apertures used to collimate the photon beam and on the machine performance. The reduction in performance during the summer of 2008

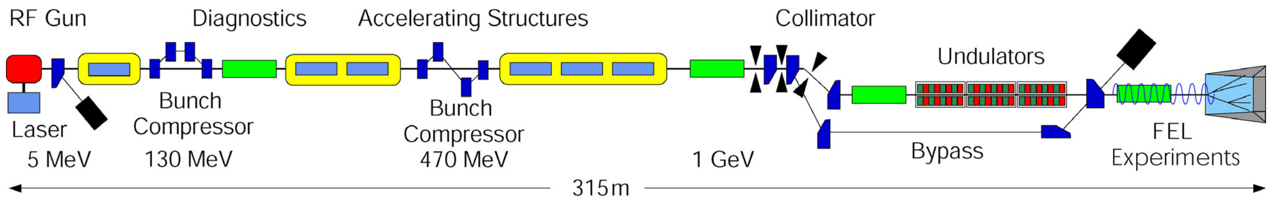

Figure 1: Schematic layout of the FLASH facility. The electron gun is on the left, the experimental hall on the right.

Table 1: Typical Photon Parameters Delivered During User Operation

Parameter	**Value**
Wavelength range (fundamental)	6.8 – 47 nm
Average single pulse energy	10 – 100 μJ
Pulse duration (FWHM)	10 – 50 fs
Peak power (from av.)	1 – 5 GW
Average power (for 500 pulses/sec)	≈ 15 mW
Spectral width (FWHM)	≈ 1 %
Peak Brilliance	10^{29} – 10^{30} B

was caused by a faulty regulation of the climatization during weeks 26 to 29 and due to failure of several components in a row during weeks 33 to 36, which resulted in an unstable operation. In addition, during the latter period a large fraction of the beam time a 1 mm aperture has been used to collimate the beam and reduce the power on purpose.

Table 2: Average Performance per User Block During the Second User Period

Year	**Weeks**	**SASE level (μJ)**
2007	48–51	18
2008	7–10	28
	14–17	22
	26–29	13
	33–36	11
	43–45	22
	48–51	34
2009	7–10	27
	14–17	23
	20–23	26
	26–28	26
	31–33	27

Since the upgrade in 2007 to an electron beam energy of 1 GeV, most users have requested either the shortest available wavelength or a wavelength around 13.5 nm, which is still often requested because of the availability of multilayer mirrors. This can be clearly seen in Fig. 2. Some users were also using either the 3^{rd} or 5^{th} harmonic of the fundamental wavelength, e.g. 2.38 (3^{rd} harmonic of 7.02 nm) or 1.59 nm (5^{rd} of 8.02 nm), corresponding to resonances. At 13.5 nm, where most operational experience since 2005 has been obtained, the facility has its best performance, as can be seen in Fig. 3. For the shortest wavelengths, more careful tuning is needed because we are approaching the limits in terms of accelerating gradients. In addition, the entire undulator length is needed in order to achieve saturation of the FEL radiation. This results in longer preparation times. Nevertheless, usually a photon pulse energy of 20 to 50 μJ can be achieved and has been delivered to users in the wavelength range from 28 to 7 nm. For longer wavelengths, the linac has to be tuned to an operation mode with little running experience. Consequently less radiation power has been delivered to users.

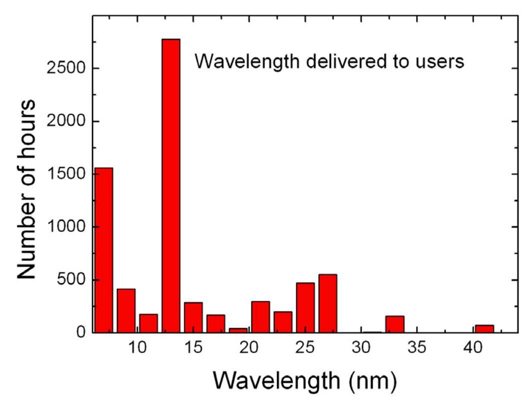

Figure 2: Wavelengths during the second user period. There is a clear preference for 13.5 nm and the short wavelengths. Part of the time, higher harmonics were used, e.g. the third harmonic of 7.02 nm and the fifth harmonic of 7.95 nm (1.59 nm).

Figure 4 shows the hours of tuning needed per week in order to change the wavelength. With the exception of one period, when two complete days were planned for tuning of the 5^{rd} harmonic of 8 nm, the tuning time is almost constant around 5 to 10 hours per week. During the weeks without tuning, the wavelength was not changed. The main improvement in tuning time is that it is now regularly done by operators instead of experts.

An example of the performance during the last three user weeks of the second period is shown in Fig. 5. After setup of the facility during the commissioning period prior to this user block, all minor adjustments to compensate for slow drifts have been done parasitically and should be automated in future by feedback systems. The lower SASE level in the middle of the period is due to smaller apertures in front of the detector.

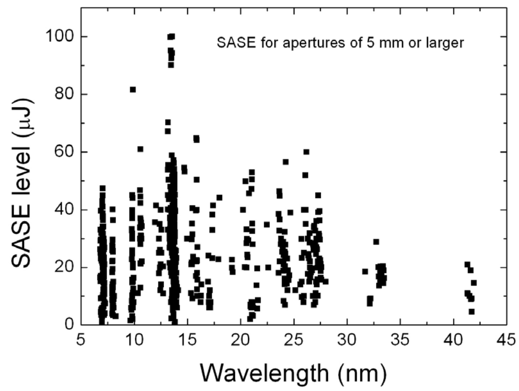

Figure 3: SASE level in μJ as a function of the wavelength. All data where apertures in front of the detector smaller than 5 mm have been used are excluded from these data set.

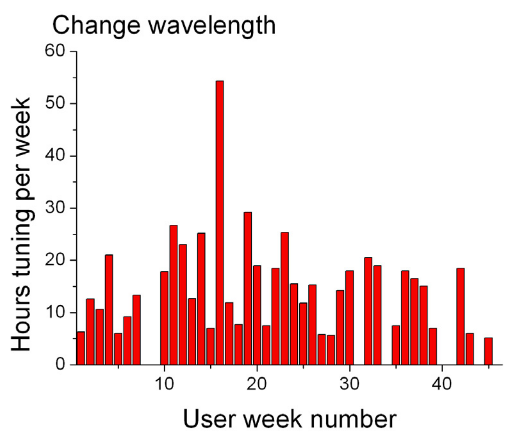

Figure 4: Number of hours used for SASE tuning each week of user operation. During certain weeks, when the wavelength was not changed, no tuning was needed. During some weeks, several shifts were scheduled for tuning in order to get optimal performance for a specific experiment.

Main Improvements to the machine during the user period 2008-2009 were:

- Cathode Laser stability (changed optics + exchanged BBO)
- Improved Low Level RF, especially for the RF gun.
- Education of operators. Keeping SASE and changing wavelength is done more regularly by a operator crew. Therefore, the experts are available more for special tuning in exceptional cases and improvements of the facility.
- Improvements of control tools/panels.

UPGRADE PLANS FOR FLASH

There is a large number of changes which will take place until spring 2010. The main changes in the tunnel are

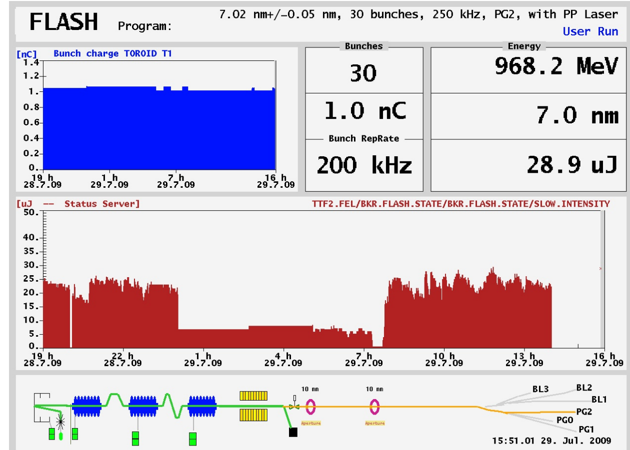

Figure 5: Performance of the FEL at the end of the user run at 7 nm. The reduction in pulse energy on July 29 is due to a 1 mm aperture in front of the detector.

- Installation the 3rd harmonic (3.9 GHz) accelerating module
- Installation of the 7th accelerating module increasing the energy up to approximately 1.2 GeV , corresponding to a wavelength below 5 nm
- Installation of an experiment for seeded VUV radiation sFLASH
- Exchange of the RF gun
- Upgrades of RF stations and waveguide distribution

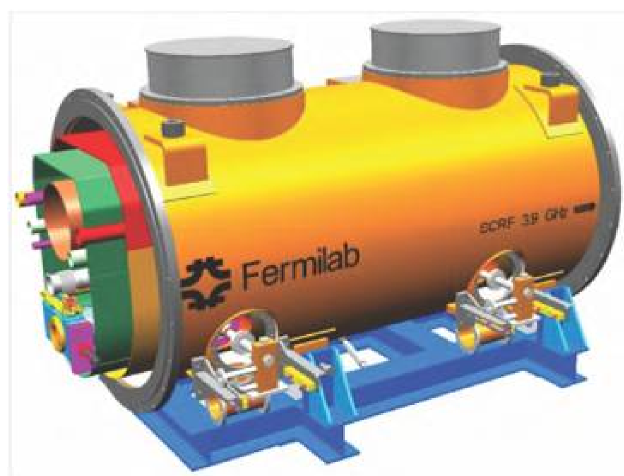

Figure 6: The 3rd harmonic accelerating cavity to linearize the phase space due to off-crest acceleration before compression in order to achieve the high peak current needed for FELs.

In order to linearize the electron phase space before compression, a third harmonic accelerating cavity will be built in behind the first accelerating module. This enables FLASH to compress a larger fraction of the electron bunch to the desired peak current and thus gives the possibility to obtain a larger bunch length with larger pulse energy. At the same time, the energy will be increased to approximately 1.2 GeV by adding an additional accelerating module. This enables FLASH to reach wavelengths below 5 nm. Because of the additional accelerating module, the waveguide distribution will be changed and an additional klystron will be used to feed modules four and five by one klystron and modules six and seven by a second one. The oldest RF stations that drive the gun and first accelerating module will be exchanged. Also the gun will be exchanged after five years of operation.

An important step towards improving the coherence properties and stability of the radiation pulses delivered to users, the sFLASH experiment will be built in the beamline between present collimator and SASE undulators to prove the feasibility of using HHG as seed for user operation [4, 5, 6]. The experiment includes an experimental station separate from the others to perform pump probe experiments with the seed laser and the seeded FEL radiation at a 10 Hz repetition rate. The implementation of sFLASH has as consequence that the complete electron beamline between collimator and SASE undulator will be re-built.

In addition, several changes are planned in the photon diagnostics area and the experimental hall.

- Focusing mirror for the beamline BL3
- Fast switching mirror between the two branches BL3 and BL1&2
- A new on-line spectrometer to measure single shot spectra based on the gas monitor detector.

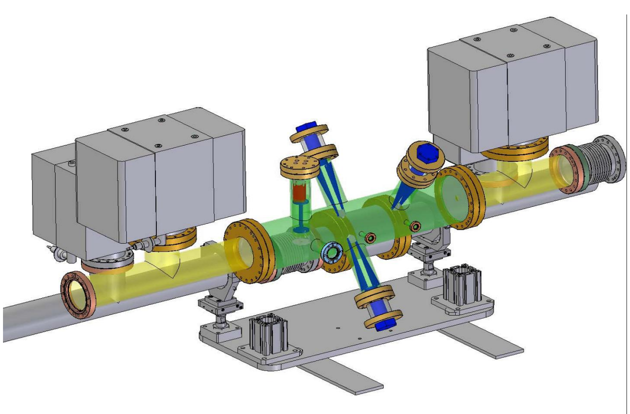

Figure 7: The new GMD based on-line spectrometer which is going to be installed in the tunnel.

SUMMARY AND OUTLOOK

FLASH has been in operation as user facility for over four years, delivering SASE of up to 100 µJ per pulse in a wavelength range down to 6.8 nm. The performance has been steadily improved and it has produced SASE at high level. In order to improve the performance further and meet user demands in the future, the wavelength range will be extended towards shorter wavelengths, the synchronization system will be improved and the RF system will be further improved. In order to decrease tuning time, an on-line spectrometer will be taken into operation such that at the same time pointing and wavelength over the pulse train can be measured simultaneously.

As a first step towards further stability and reproducibility of the FEL, an HHG seeding scheme called sFLASH will be taken into operation with a separate experimental station for pump-probe experiments. For the longer term a second undulator line is proposed with a variable gap undulator reaching the water window which will be seeded to serve an ever increasing community of users with a system synchronized on the femtosecond level with a pump-probe laser.

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