

FLASH UPGRADE

K. Honkavaara*, B. Faatz, J. Feldhaus, S. Schreiber
 DESY, Hamburg, Germany
 J. Rossbach, University of Hamburg, Germany

Abstract

The free-electron laser FLASH at DESY is the world-wide leading FEL user facility operating in the VUV and the soft X-ray wavelength range. Since summer 2005, FLASH has provided coherent femtosecond laser radiation for user experiments with photon wavelengths from 47 nm to 6.8 nm in the fundamental. Autumn 2009, FLASH will be upgraded with an additional superconducting TESLA type accelerating module boosting the electron beam energy up to 1.2 GeV. This will allow lasing with wavelengths below 5 nm. In addition, a module with four third harmonic superconducting cavities will be installed to linearize the longitudinal phase space and thus to improve the overall performance of the facility.

INTRODUCTION

FLASH, the free-electron laser facility at DESY (Hamburg, Germany), is a world-wide unique light source providing ultrashort radiation pulses for user experiments in the femtosecond range with an unprecedented peak brilliance.

FLASH is based on the TTF-FEL [1] operated at DESY until end 2002 with photon wavelengths from 120 nm to 80 nm [2, 3]. In 2003-2004, the TTF-FEL facility was redesigned, upgraded, and commissioned to an FEL user facility. The new facility, FLASH, has an optimized injector section to produce high quality electron beams, initially five TESLA type accelerating modules to achieve an electron beam energy of 800 MeV, a 30 m long undulator section to produce SASE (self amplified spontaneous emission) FEL radiation, and an experimental hall with five photon beamlines. The first lasing at 32 nm has been achieved in January 2005 [4]. Since summer 2005 FLASH is a user facility. The smallest achievable photon wavelength at that time was 13 nm [5]. In summer 2007, an additional accelerating module has been installed to increase the electron beam energy to 1 GeV corresponding to a photon wavelength of 6.5 nm [6, 7]. Operational experience gathered at FLASH during the last couple of years are reported in [8, 9, 10].

The second FEL user period will continue until August 2009. It is followed by a dedicated experiment to operate the FLASH linac with 800 μ s long electron bunch trains with a beam current of 9 mA.[11]

In order to further improve the performance of the FLASH facility, an upgrade is scheduled for autumn 2009.

A seventh accelerating module will increase the beam energy to 1.2 GeV. A third harmonic module will be added to the injector upstream the first bunch compressor. An experiment for seeded VUV radiation (sFLASH) will be installed as well. Several other upgrades are scheduled: the RF gun and the first accelerating module will be exchanged, and the RF stations and the waveguide system will be upgraded and optimized. Fig. 1 shows the layout of FLASH after the 2009 upgrade.

PRESENT LAYOUT

The FLASH injector consists of a laser driven RF gun, an accelerating module, and a chicane type bunch compressor. The RF gun is a 1.5 cell normal conducting L-band cavity. The electron beam energy is boosted to 130 MeV by the first accelerating module. The module, as well as all the other FLASH accelerating modules, is a 12 m long TESLA type superconducting module with eight 9-cell niobium cavities operated at 1.3 GHz.

The injector is followed by two accelerating modules to increase the energy up to 470 MeV before the second bunch compressor. Three further modules accelerate the electron beam up to 1 GeV.

The SASE FEL radiation is produced by a 30 m long undulator section. The produced radiation is guided via a photon transport line to the experimental hall, where five beamlines have been set-up for user FEL experiments.[12]

The FLASH linac and its electron beam parameters are described in more detail in [8, 9, 10].

BUNCH COMPRESSION AND THE THIRD HARMONIC MODULE

Peak current, transverse emittance, and energy spread are the most relevant electron beam parameters for a SASE FEL. At FLASH, two magnetic chicane bunch compressors are used to reach the required peak current of ~ 2 kA. Optimization of the emittance in the RF gun requires long initial electron bunches (~ 2 mm). When a long bunch is accelerated off-crest by the sinusoidal RF field of the accelerating module, a non-linear energy chirp is produced along the bunch. The compression process leads therefore to a non-symmetrical longitudinal bunch shape with a leading high current peak and a long tail.

Only a fraction of the compressed electron bunch contributes to the lasing process (about 20 to 30%): the part which has simultaneously a high peak current, a small energy spread, and a small emittance. Since only a fraction

*katja.honkavaara@desy.de

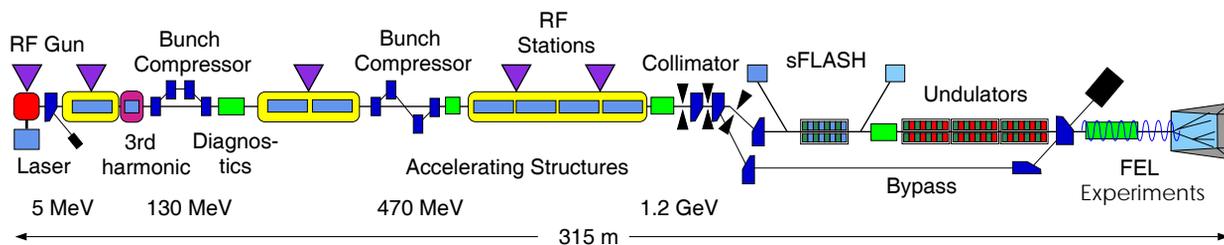


Figure 1: Layout of FLASH after the 2009 upgrade (not to scale).

of the bunch produces FEL radiation, the duration of the radiation pulses is very short: in the range of 10 to 50 fs.

Many FEL experiments rely on the extremely short and high brilliance photon pulses. Other experiments, however, would profit from a substantial increase of the single pulse energy. To increase the pulse energy by an order of magnitude, a better control of the longitudinal phase space is required. In the presently applied femtosecond operation mode, the lasing part of the beam is not accessed by standard electron beam diagnostics like beam position monitors. Most diagnostic devices measure only projected parameters. As an example, the measured orbit must not correspond to the orbit of the lasing part of the electron beam. This heavily complicates the tuning procedures.

The RF curvature, causing the non-symmetrical compressed bunch shape described above, can be removed by third harmonic cavities. During the 2009 shutdown, a module with four superconducting cavities operated at 3.9 GHz (third harmonic of 1.3 GHz) will be installed upstream of the first bunch compressor. This module has been designed and constructed within a collaboration between DESY and FNAL. It comes with a new 3.9 GHz klystron and modulator, as well as a dedicated low level RF regulation. More details can be found in [13].

When operating the third harmonic module, the longitudinal shape of the compressed bunch is expected to be more regular. As a consequence, we expect that a larger fraction of the bunch charge develops a high peak current, and thus contributes to the lasing process. The tuning will be easier, since then the projected beam parameters represent better the lasing part of the beam. A significant increase in FEL radiation pulse energy by up to a factor of 10 is predicted by simulations [14]. On the other hand, the FEL pulse duration is expected to increase to ~ 200 fs [14].

With the third harmonic module switched off, FLASH will be operated in the present femtosecond mode. Intermediate modes are also anticipated providing more flexible beam parameters for user experiments.

ENERGY UPGRADE

A seventh TESLA type accelerating module will be installed autumn 2009. With this upgrade, we expect a maximum electron beam energy of ~ 1.2 GeV. Space for the seventh module has been foreseen from the beginning. However, adding more modules would require a major re-

arrangement of the linac.

After the energy upgrade, we expect lasing below 5 nm approaching the water window. The lasing performance mainly depends on the electron beam parameters in terms of peak current and emittance, which we expect to be just sufficient for saturation at 5 nm. If required, the RF gun will be upgraded with a 10 MW klystron, and also an additional undulator module may be installed later.

SFLASH SEEDING EXPERIMENT

A seeding experiment, sFLASH, will be installed in the section between the accelerator and the SASE undulators. This experiment, designed and constructed by the University of Hamburg in collaboration with DESY, consists of a seed laser beam line, an undulator section of 10 meters, a weak magnetic chicane to separate the electron beam and the FEL radiation, and a photon beam line to transport the FEL radiation to an experimental hutch located outside the FLASH tunnel. A detailed description of sFLASH can be found in [15, 16].

In order to realize the sFLASH experiment, 40 meters of the FLASH electron beam line need to be reconstructed. Several new components, e.g. four variable gap undulators, will be installed, and the existing components, like quadrupole and steerer magnets and electron beam diagnostic devices, will be moved to new locations. The sFLASH design has taken care of not to disturb the standard SASE operation.

TRANSVERSE DEFLECTING CAVITY

A transverse deflecting RF cavity is an important tool to measure the longitudinal structure of electron bunches as well as the slice beam parameters. At FLASH, these measurements will be especially important during the commissioning of the third harmonic module.

The FLASH transverse deflecting structure LOLA [17], presently in operation downstream the accelerating modules, will be moved to a new location close to the SASE undulators. A dispersive section will be added to allow a complete measurement of the longitudinal phase space. To gather additional information, a new THz-spectrometer will be installed as well.

The goal is to operate LOLA as a monitor in parallel to SASE operation. The beam optics design takes into

account a good resolution for LOLA measurements and matching to the SASE undulators at the same time. A fast kicker will kick one bunch of a bunch train onto an off-axis OTR screen, while the remaining bunches continue through the undulators for lasing.

OTHER UPGRADES

The RF gun has been in continuous operation over the last five years. The area around the cathode, especially where the RF contact spring is located, shows signs of aging. A visual inspection in May 2008 showed small damages at the groove holding the RF contact spring. The darkcurrent level is quite high although still acceptable for operation.[18] Therefore we decided to replace the RF gun by a new gun tested at PITZ. It has an improved cooling scheme allowing an operation with more RF power. The RF station will be prepared to be operated with a 10 MW klystron. More important, the darkcurrent will be much reduced due to the new dry ice cleaning technique.[19]

The first accelerating module is planned to be exchanged by a new module with improved performance. The new module will provide higher accelerating gradients to compensate the loss of electron beam energy with the third harmonic module in operation. The new cavities are also equipped with piezo tuners.

In order to optimize the performance of all seven accelerating modules, a fifth RF station will be connected to the FLASH linac. The RF gun and the first module will be operated, as presently, by one 5 MW klystron each. The second and third module will have a common 5 MW klystron, as well as the fourth and fifth module. The sixth and seventh module will be operated by one 10 MW multibeam klystron.

The two RF stations feeding the RF gun and the first accelerating module have been in operation since more than 10 years. They have been provided by FNAL within the TESLA collaboration for the TESLA Test Facility. Despite their excellent performance, acquiring spare parts is becoming more and more difficult. The modulators and transformers will be replaced to be compatible with the other three RF stations. With the upgrade we expect easier operation and maintenance, together with an overall improvement in reliability.

Similar to module 6, the new acceleration module 7 will have an XFEL-type waveguide distribution [20]. This distribution allows the adjustment of power levels for individual cavities, and thus optimization of the performance of the complete module.

SUMMARY AND OUTLOOK

An upgrade of the FLASH facility is scheduled for autumn 2009. The energy will be upgraded to 1.2 GeV with an additional accelerating module. Superconducting third harmonic cavities will allow a more flexible tuning of the longitudinal phase space. A seeding FEL experiment,

sFLASH, will be installed as well. The RF gun and the first accelerating module will be exchanged, and the RF stations and the waveguide distribution will be upgraded. The transverse deflecting structure LOLA will be relocated, and a short dispersive section will be added to it.

The five months shutdown will be followed by a commissioning period to reestablish SASE operation with the highest electron beam energy and the smallest wavelength. We plan also to spend a considerable amount of time in shaping the longitudinal phase space with the new third harmonic module. Special commissioning time will be granted to the sFLASH experiment. The FEL user operation of the upgraded FLASH facility is expected to start in summer 2010.

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