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UPGRADE PLANS FOR FLASH FOR THE YEARS AFTER 2020

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Abstract

FLASH is a unique superconducting soft X-ray free-electron laser (FEL) capable of producing up to 8000 photon pulses per second. A substantial upgrade is planned to keep FLASH a state of the art FEL user facility. The current upgrade scenario according to the FLASH 2020+ conceptual design report is discussed.

INTRODUCTION

The superconducting free-electron laser user facility FLASH [1–3] at DESY in Hamburg routinely delivers several thousand high brilliance XUV and soft X-ray photon pulses per second. The user facility FLASH is in operation since 2005 and since 2014 the bunch train from the superconducting linac can be split between the original FLASH1 undulator beamline and a new second beamline FLASH2. In the following, the terms *FLASH1* and *FLASH2* will refer to these beamlines while the term *FLASH* will either refer to the complete FLASH facility or the common injector and linac complex of FLASH whenever the context makes this abbreviation non-ambiguous. A detailed overview of the history and the technical evolution of FLASH can be found in [4, 5] and a more detailed description of the layout can be found in [6, 7].

In 2016 a significant *Mid Term Refurbishment Program* was started for FLASH. Its program will persist for the next years. As part of the DESY strategy process *DESY 2030* [8] that was initiated 2016, a second substantial upgrade, FLASH 2020+ was proposed [9]. In April 2019 the internal conceptual design report (CDR) for FLASH 2020+ [10] was finalized. In the following, we briefly summarize the accelerator related aspects of the FLASH 2020+ CDR.

MID TERM REFURBISHMENTS

A refurbishment program was initiated to replace aged and outdated equipment, to adapt the diagnostic hardware to the changed constraints due to low charge operation, and to start implementing upgrades essential to a modern FEL user facility. As an example, the electron beam diagnostics was designed for bunch charges of >1 nC, but FLASH is now routinely operated with 300 pC or less. The refurbishment consists of various items of different impact and complexity and is not yet completed in all its aspects.

Already Implemented / Started

FLASH2 was equipped with beam position monitor (BPM) electronics suitable for low charge operation already during its assembly in 2013. In a first step all existing FLASH/FLASH1 BPM electronics where upgraded for low charge operation which at the same time provided a significantly better resolution [11]. New toroids have been installed improving the charge resolution by an order of magnitude well below 1 pC. In a second step the bunch arrival time monitors (BAMs) have been replaced with detectors suitable for <100 pC bunch charge, and the electro-optical front-ends are being replaced with upgraded ones [12] providing better resolution at lower bunch charges. The BAM upgrade is combined and in fact relies on the ongoing upgrade of the optical synchronization system. This system not only provides a drift compensated reference for the timing of the BAMs and other highly timing sensitive diagnostics, but is used to synchronize the optical pump probe lasers of the experimental halls of FLASH1 and FLASH2. In order to enhance the gain of the intra train bunch arrival time feedback, a normal-conducting high-bandwidth S-band cavity (BACCA, see Fig. 1) was installed downstream of the 3.9 GHz longitudinal linearizer module [13]. The commissioning of the cavity has started.

In order to characterize the longitudinal phase space and the slice emittances of the FLASH2 bunches as well as obtaining estimates on the FLASH2 photon pulse duration [14], a newly designed transverse deflecting X-band structure [15, 16] (PolariX-TDS, see Fig. 1) will be installed downstream of the FLASH2 undulators in 2020. In mid-2019, the prototype of the TDS will be installed in the FLASH3 beamline for the plasma wakefield acceleration experiment *FLASHForward* [17].

A third, independent bunch compressor chicane will be installed at the end of the FLASH2 extraction arc (i.e. at full beam energy, see Fig. 1) to ameliorate the effects of space charge of the FLASH bunch compression chain at low energy and the effects of coherent synchrotron radiation (CSR) in the FLASH2 extraction arc. The potential enhancement of beam quality (slice energy spread- and slice emittance preservation and linearity of the compression) is discussed in detail in [18].

In Preparation / Planned

A key aspect of the refurbishment plan is the replacement of the two oldest and weakest superconducting accelerating modules (2nd and 3rd in injector, see Fig. 1) with modern prototype modules designed for the European XFEL. The two modules are currently being refurbished with new high gradient cavities and it is planned to install them in 2021. Moreover, the klystron driving the modules will be moved closer to the location of the modules thereby reducing the length and the losses in the waveguide system. The plan is to increase the beam energy in the second compressor chicane by at least 100 MeV to 550 MeV. In addition it is planned to optimize the waveguide distribution system for the cavities

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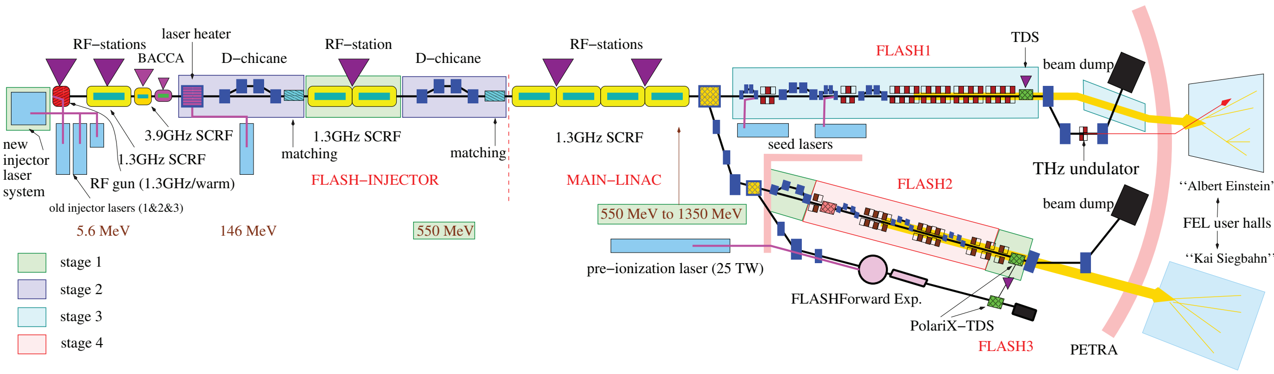

Figure 1: Planned layout of the upgraded FLASH facility according to the FLASH 2020+ CDR. The current layout for comparison is shown in [6]. Not to Scale. The various upgrade stages are indicated by shaded boxes.

in the first two modules in the main linac. These changes constitute an *energy upgrade* to a maximum beam energy of 1350 MeV.

The existing 3 injector lasers (Fig. 1) provide great flexibility concerning bunch pattern and charge distribution and are so far extremely reliable. However, certain key components are meanwhile difficult to maintain. Thus a new injector laser system is being designed which will be installed in a new laser hut (Fig. 1) while the old lasers can still operate in the existing hut.

A new RF gun with enhanced heat transport properties and two (instead of one) RF power couplers is under construction [19]. With this new gun we intend to reliably reach the full design pulse duration of 800 μs in stable operation.

A helical undulator in an afterburner configuration will be installed in the FLASH2 beamline to generate circular polarized SASE radiation enabling explicit control of the photon polarization.

THE FLASH 2020+ PROPOSAL

The FLASH 2020+ proposal is motivated by the requests of the user community, taking into account the technological and beam physics requirements and constraints. Many details of the upgrade go beyond the scope of this contribution and are so far only described in the internal FLASH2020+ CDR [10]. There are several key aspects of the upgrade: Firstly, in order to enhance the independence of the two beamlines and their over all operability, FLASH1 needs to be equipped with variable gap undulators. Secondly high repetition rate seeding will be established in the FLASH1 beamline with the goal of 1 MHz seeding. Thirdly, the lower wavelength limit of FLASH2 in the fundamental is to be extended down to the oxygen K-edge (2.3 nm) in order to reach the important elements for energy research and to cover the whole water window for biological questions. Fourthly, novel lasing concepts are discussed to be implemented in the FLASH2 beamline. An important goal here is to make attosecond science at FLASH possible. This is discussed in [20].

All these aspects require enhanced beam quality in terms of highly linearized core compression, and excellent preservation of slice energy spread and slice emittances. Moreover, in order to maintain stability and operability of the new FEL modes, measures have to be taken to improve the machine set up procedures of FEL operation. Stable seeding is basically impossible in the presence of fluctuating micro bunch structures. Those can be amplified from small charge inhomogeneities from the source by the micro bunching gain mechanism (see e.g. [21, 22]) in FELs with cascaded magnetic bunch compression stages. Therefore installation of a laser heater (see Fig. 1), capable of inducing an energy modulation amplitude of 35 keV, upstream of the first compression chicane is planned. A 515 nm laser will modulate the electron bunches in a small 8 to 10 period undulator (period length 40 mm, $K = 1.3$). In order to generate space for the laser heater, the first bunch compressor chicane will move downstream and the following matching section downstream will be optimized and shortened.

In the present configuration there is no proper matching section downstream of the second bunch compression chicane. For the upgrade the present S-type (6 magnet) chicane will be replaced by a D-type (4 magnet) chicane with slightly reduced longitudinal dispersion ("R_{56}") to generate space for a section suitable for multi-quadrupole scans and rematching into the downstream optics. The changes to optics and compression scheme are described in full detail in [18].

In order further improve the beam quality for FLASH1 it is planned to remove the dogleg-shaped energy collimation section downstream of the main linac and thereby shift the complete FLASH1 undulator beamline by 40 cm towards the tunnel center. Compare the upgraded layout in Fig. 1 to the present layout in [6, 23]. Downstream the FLASH1 undulators, a small dogleg section will separate the electron beam from the photon beamline and then guide the electron beam towards the beam dump — similar as it is already realized in FLASH2. The FLASH1 TDS and the THz-Undulator will be moved to this section. In the same process the FLASH1 photon beamline and diagnostics will be upgraded.

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Possible Stages of Realization

Here we will describe a possible scenario for dividing the full upgrade into several stages, so that each stage by itself implies a consistent upgrade step and so that the functionality of each stage is independent of *later* stages. The sections containing (easily localizable) upgrades are indicated in Fig. 1 by shaded boxes in colors referring to the 4 main upgrade stages.

The *first stage* is the implementation of the upgrades from the mid term refurbishment program that are prerequisite to the FLASH2020+ proposal. This includes the energy upgrade, the new FLASH2 compressor chicane, and the PolariX-TDS for FLASH2.

The *second stage* includes the modifications of the first and second bunch compressor chicanes and the installation of the laser heater. In addition the new injector laser system will be installed in a new hut outside the hall housing the FLASH injector and is thus mostly independent of other FLASH activities.

The *third stage* is the remodeling of the FLASH1 beamline in various extensions. The replacement of the fixed gap undulators with variable gap ones is most urgent. Once the beamline is set up for seeding, the upgrade of the seed lasers to higher repetition rate can be done almost at any time with only little implications on the FLASH schedule. In a first phase, 100 kHz is envisaged followed by an upgrade to the full 1 MHz matching the full bunch repetition rate of the electron beam. Note that the seeding repetition rate is within the FLASH time structure completely restricted by the seed lasers.

Finally, *stage four*, the implementation of novel lasing schemes in FLASH2 will finalize the FLASH2020+ project.

Our vision is, that FLASH will be the first seeded high repetition rate XUV and soft X-ray FEL.

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