ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF089

POSSIBLE UPGRADES OF FLASH — A VIEW FROM THE ACCELERATOR-PERSPECTIVE

M. Vogt*, B. Faatz, K. Honkavaara, J. Roensch-Schulenburg, S. Schreiber, J. Zemella
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany, EU

Abstract

Recently FLASH (Free electron LASer in Hamburg) at DESY has been granted funding for a refurbishment project covering among others the replacement of two old SRF modules, an upgrade of the injector lasers and an upgrade of parts of the electron beam diagnostics. In addition we are proposing several possible upgrades and new features for the injector and the drive linac as well as in the undulator beamlines. Here we present options which are in our opinion technically feasible and at the same time operationally manageable.

INTRODUCTION

FLASH [1–5] is a superconducting linac driving two FEL beamlines in the XUV and soft X-ray regime. It can produce several thousand photon pulses per second and distribute them between two photon beamlines, both served with bursts of potentially several hundred pulses at 10 Hz burst repetition rate. A detailed overview of the history and the technical evolution of the FLASH facility can be found in [6], a detailed description of the principal layout of FLASH can be found in [7] with recent modifications described in [1, 3], and with a table of the most recent run parameters in [3]. There is an ongoing refurbishment project and certain parts of the new hardware have already been installed while other components are planned for installation in the next couple of years. These installations are discussed in the next section. In addition, further upgrades are under discussion (FLASH 2020+ project). In this paper we present ideas on modifications of the bunch compression scheme and lattice design. It is clear that an upgraded FEL facility requires reliable and stable delivery of high quality beams to the undulator beamlines. At FLASH2 the variable gap undulators have shown their potential for enhancing the flexibility of tuning of the photon beam parameters. In order to use the full capacity of the FLASH facility and ease its operation, it is inevitable to replace the FLASH1 fixed gap undulators by undulators with a variable gap.

ONGOING REFURBISHMENT PROJECTS

This section summarizes the ongoing refurbishments at the FLASH facility.

The original FLASH electron diagnostics was designed for bunches of more than 1 nC. Many user request short FEL pulses, which are achieved by compressing bunches of sigificantly lower charge (down to 60 pC). Thus an essential part of the refurbishment is to upgrade the electron diagnostics in FLASH for low charge operation. The beam position monitors and the beam loss monitors are all upgraded by now. The upgrade of the beam arrival time monitors [8] and the optical synchronization system is ongoing. The two 1.3 GHz modules between the first and the second bunch compressor chicane are among the first superconducting L-band modules ever built at DESY and despite the fact that they have served reliably for more than 10 years, we are planning to replace them with new XFEL type modules with selected high gradient cavities. In the optimal case one could achieve an energy gain of ~400 MeV — compared to ~300 MeV now. Without adding additional modules these ~100 MeV are the limit for an energy upgrade. Since the new XFEL modules are designed for a FODO optics (one quadrupole per module) while the old FLASH modules where equipped with a doublet each, optics modifications are necessary in the matching section between the modules and the second chicane. It is expected that certain spare parts for the two standard injector lasers will become inaccessible in the foreseeable future. Therefore, at some stage, the injector lasers will be replaced by new ones provided by the DESY Laser group.

FLASH2 [9] and FLASHForward [10] will be equipped with an advanced X-band transverse deflecting structure with variable polarization called PolariX-TDS [11, 12] to monitor the electron longitudinal phase space. At FLASH2 two PolariX-TDS modules located downstream of the undulator will enable an estimate on the actual photon pulse duration.

TOWARDS FLASH 2020+

In this section we discuss new ideas on a lattice redesign as well as first results of optics design and tracking simulations. The proposed modifications, including those from the refurbishment project, are visualized in Fig. 1.

In order to improve the control over slice energy spread and micro bunching we are planning to install a laser heater in the section between the 3.9 GHz linearizer and the first bunch compressor chicane. The actual design of the laser heater is not yet decided. We are foreseeing enough matching quadrupoles around the chicane to measure emittance and mismatch downstream of the chicane using the standard four screen method and to control the match of the space charge dominated bunch from the gun into the design optics already upstream of the chicane. In order to gain space for better optics control we are planning to replace the S-type chicane (6 dipoles, $R_{5,6} \approx 80$ mm) of the second bunch compression stage by a D-type chicane (4 dipoles, approximately same $R_{5,6}$). This will enable us equip the section after the second

* vogtm@mail.desy.de

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF089

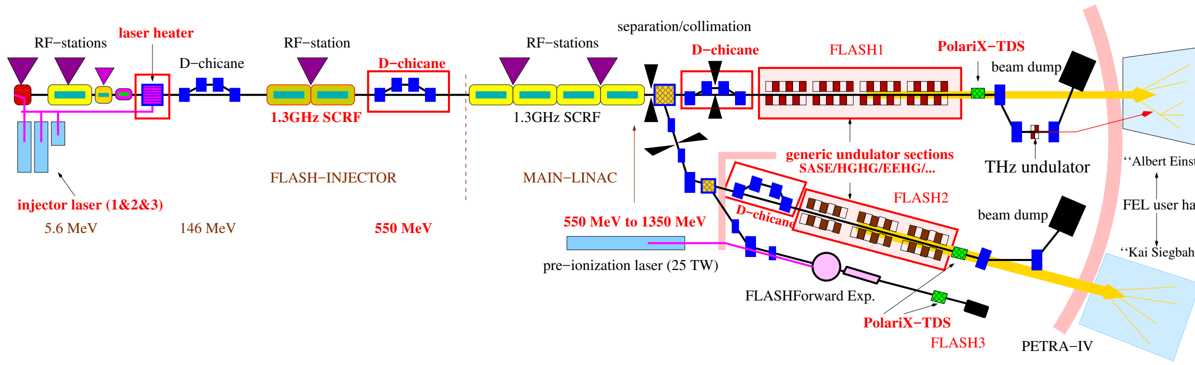

Figure 1: A possible scheme for the upgraded FLASH facility. Upgrade ideas are marked in red. Changes of the focusing lattice and changes of the beam optics are *not* indicated.

chicane with an optics suitable to routinely control emittance and mismatch using an optimized multi-quad scan.

FLASH1 has a dispersive dogleg arc with energy collimators after the main linac to protect the undulators. We propose to remove this dogleg from its present position and replace it with third (for FLASH1) D-type bunch compressor chicane ($R_{5,6} \approx 20$ mm). This will give us more flexibility in choosing the compression working point and i.p. will allow for weaker compression at the low energy stage. The collimator system will be changed and its flexibility will be enhanced. Removing the dogleg will shift the FLASH1 undulator beamline horizontally by 40 cm.

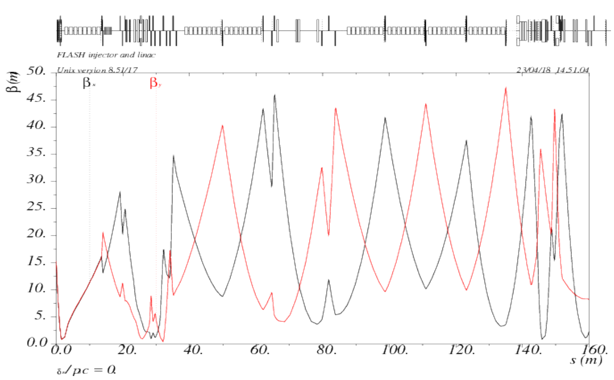

Figure 2: The upgraded optics in the FLASH injector & linac.

The FLASH2 extraction arc is not changed, but FLASH2 will also be equipped with a third compressor chicane ($R_{5,6} \approx$ 12 mm) immediately downstream of the extraction into FLASH3. Analogously to FLASH1 this will ameliorate the beam degradation through collective effects during the bunch compression process. In particular the FLASH2 extraction arc will be passed with lower peak current. We hope to install the third FLASH2 chicane within the next couple of years to allow us gaining operational experience with the concept of 3-stage bunch compression.

The FLASH1 undulators will be replaced by variable gap ones within the FLASH 2020+ project. The concept and layout of the undulator beamlines at FLASH1 and FLASH2 is presently under consideration and can thus not be presented here. It is proposed to install one or two PolariX-TDS modules in FLASH1 downstream of the undulator section, followed by a horizontal dogleg, equivalent to the dogleg that we plan to removed from upstream of the undulator beamline. The dispersion inside the dogleg will be employed for the dispersive arm of the PolariX-TDS diagnostics. Moreover the new dogleg will horizontally shift the beam back by 40 cm into the old transport line to the dump. It is planned place the THz undulator downstream of the dogleg to decouple the XUV and THz beamlines.

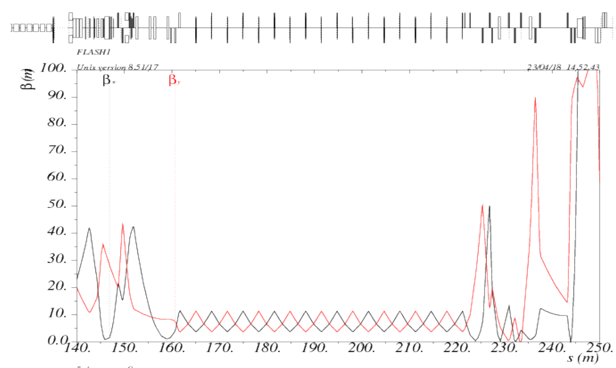

Figure 3: The upgraded optics in the FLASH1.

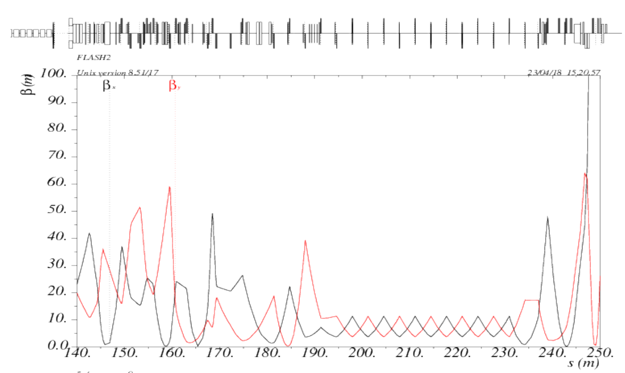

Figure 4: The upgraded optics in the FLASH2.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF089

Figures 2, 3, and 4 show the proposed optics in the FLASH injector/main-linac, FLASH1, and FLASH2 respectively. The dump sections are cut out because their beta functions, blown up to minimize the beam intensity on the dump window, would completely dominate the vertical scale. Downstream of the provisional undulator optics, both FLASH1 and FLASH2 contain a section optimized for two PolariX-TDS modules. The FLASH1 beamline contains an additional section optimized for housing a THz undulator. Figures

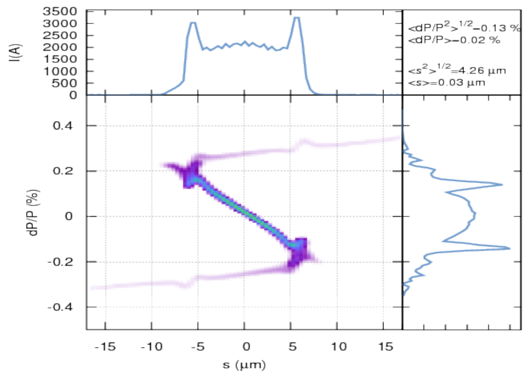

Figure 5: Long. PS: 100 pC upstream FLASH1 undulator.

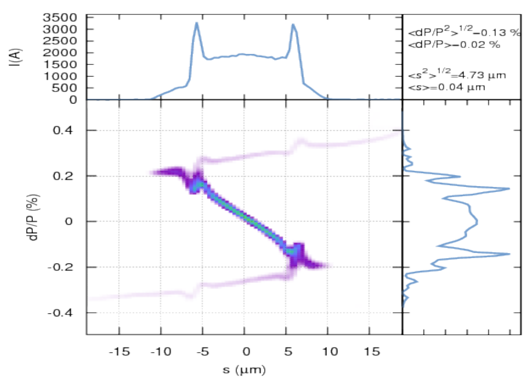

Figure 6: Long. PS: 100 pC upstream FLASH1 undulator.

5, 6, 7, and 7 show the result of tracking simulations using the nonlinear collective tracking codes ASTRA [13] and X-Track [14]. A bunch of 100 pC was tracked using ASTRA to upstream of the first cavity. From there it was tracked using X-Track to upstream of the FLASH1/2 undulators, thereby compressed to a peak-current (inside the bunch core) of 2 kA. Space charge (3D), CSR and cavity wakes were taken account. The trace space emittance was 0.4 μm mrad after the 1st RF module. Figures 5 and 6 show the longitudinal phase space (PS) of the tracked bunches for FLASH1 and FLASH2 respectively. Note the beautifully linear energy chirp in the cores of the bunches. Figures 7, and 7 show the the horizontal and vertical phase space for the FLASH2 bunch. Table 1 contains a summary of the tracking data. Note the preservation of the projected emittance $\epsilon^{\text{norm,proj}}$ and the small relative slice-energy spread $\sigma_\delta^{\text{slice}}$ the small slice emittances $\epsilon^{\text{norm,slice}}$.

Table 1: Tracking Results

Quantity	FLASH1	FLASH2
$\sigma_\delta^{\text{slice}}$ /10^{-5}	3.5 - 6.5	3.5 - 6.5
$\epsilon_{x=y}^{\text{norm,slice}}$ /μm mrad	0.3 - 0.35	0.25 - 0.35
$\epsilon_x^{\text{norm,proj}}$ /μm mrad	0.5	0.5
$\epsilon_y^{\text{norm,proj}}$ /μm mrad	0.4	0.4

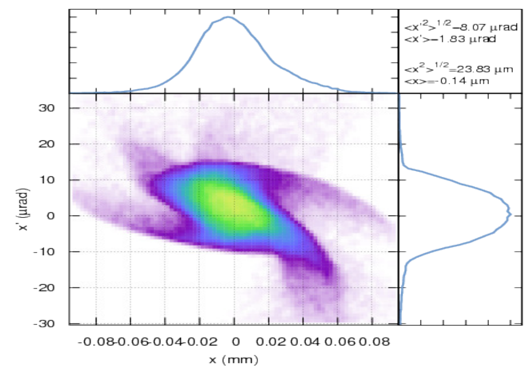

Figure 7: Hor. PS: 100 pC upstream FLASH2 undulator.

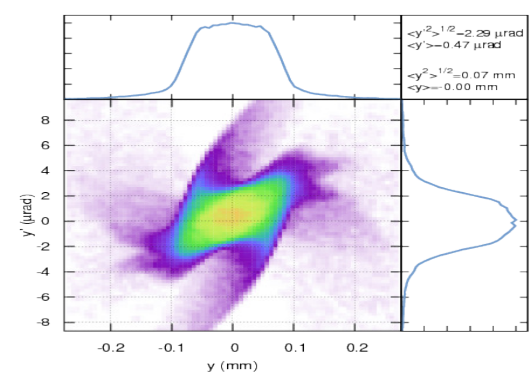

Figure 8: Vert. PS: 100 pC upstream FLASH2 undulator.

SUMMARY

FLASH has been successfully providing XUV pulses of high brilliance and/or extreme short duration in rates of several thousand per second for more than 10 years. Although the design phase of the possible upgrades is not yet finished, we have reported here on ideas from the machine perspective on how to reliably provide high quality beams within the boundaries of what is technically and operationally feasible. We see the potential for an electron beam energy upgrade by ~100 MeV and have developed a new improved lattice that is better suited to preserve the excellent beam properties from the gun during acceleration and charge compression. We have foreseen advanced diagnostics to characterize and optimize the bunches at the undulators, i.e. the location where the actual FEL process is situated.

REFERENCES

[1] M. Vogt, et al., "Status of the Superconducting Soft X-ray Free-Electron Laser FLASH at DESY", TUPMF090, *These*

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF089

Proceedings, IPAC'18, Vancouver, BC, Canada, (2018).

[2] K.Honkavaara, "Status of the FLASH FEL User Facility at DESY", MOD02, FEL'17, Santa Fe, NM, USA (2017).

[3] M.Vogt et al., "Status of the Soft X-ray Free Electron Laser FLASH", WEPAB025, IPAC'17, Copenhagen, Denmark (2017).

[4] B.Faatz, E.Plönjes, et al., "Simultaneous Operation of Two Soft X-Ray Free-Electron Lasers Driven by One Linear Accelerator", *New J. Phys.* **18** 062002 (2016).

[5] S.Schreiber and B.Faatz, "The Free-Electron Laser FLASH", *High Power Laser Sci. and Eng.*, **3**, e20, doi:10.1017/hpl2015.16, (2015).

[6] K.Honkavaara et al., "FLASH: First Soft X-Ray FEL Operating Two Undulator Beamlines Simultaneously", WEB05, *Proc.* FEL'14, Basel, Switzerland (2014).

[7] M.Vogt et al., "Status of the Free Electron Laser User FLASH", TUOCA02, *Proc.* IPAC'14, Dresden, Germany (2014).

[8] M.Viti, et al., "Recent Upgrades of the Bunch Arrival Time Monitors at FLASH and European XFEL", MOPIK072, IPAC'17, Copenhagen, Denmark (2017).

[9] F.Christie, et al., "Generation of Ultra-Short Electron Bunches and FEL Pulses and Characterization of their Longitudinal Properties at FLASH2", WEPAB017, IPAC'17, Copenhagen, Denmark, (2017).

[10] R.D'Arcy, et al., "Longitudinal Phase Space Reconstruction at FLASHForward Using a Novel X-Band Transverse Deflection Cavity, PolariX-TDS", TUPML017, *These Proceedings*, IPAC'18, Vancouver, BC, Canada, (2018).

[11] P.Craievich. et al., "Status of the PolariX-TDS Project", THPAL068, *These Proceedings*, IPAC'18, Vancouver, BC, Canada, (2018).

[12] B.Marchetti, et al., "X-Band TDS Project", MOPA044, IPAC'17, Copenhagen, Denmark (2017).

[13] K.Flöttmann, "ASTRA A Space Charge Tracking Algorithm", `http://www.desy.de/~mpyflo/`, (2017).

[14] M.Dohlus "X-Track", Tracking code developed at DESY, to date unpublished (2017).