THE NEW FLASH1 BEAMLINE FOR THE FLASH2020+ PROJECT

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Abstract

The 2nd stage of the FLASH2020+ project will be an upgrade of the FLASH1 beamline, downstream of the injector/linac section FLASH0 which is currently being upgraded. The currently existing beamline drives the original planar fixed gap SASE undulators from the TTF-2 setup, a THz undulator that uses the spent electron beam and deflects the e-beam into a dump beamline capable of safely dumping several thousand bunches per second. The updated beamline has been designed for EEHG seeding with 2 modulators, 3 chicanes, and a helical Apple-III undulator beamline as seeding radiator, followed by a transverse deflecting (S-band) structure for longitudinal diagnostics. The separation of the electron beam from the FEL beam will be moved upstream w.r.t. the old design to create more space for the photon diagnostics and will be achieved by a 5deg double-bend-almost-achromat. To allow enable high power THz radiation output from a moderately compressed seeding beam, a post compressor will be installed. The capability of dumping the the long bunch trains safely may and will not be compromised by the design. This article describes the beamline concept and some details on the part downstream of the radiator.

INTRODUCTION

FLASH the, Free-electron LASer in Hamburg [1, 2], is currently undergoing a substantial upgrade and refurbishment project, FLASH2020+ [3, 4]. Flash consists of four functionally distinct sections: the common part (injector, linac), called FLASH0, the two independent undulator beamlines FLASH1 & FLASH2, and the experimental beamline FLASH3. The superconducting linac supplies sufficiently long RF pulses (flat top for beam operation up to 800 µs), to serve both, FLASH1 and FLASH2, with sub-trains of up to several hundred bunches at every RF-pulse. The pulse repetition frequency is 10 Hz.

While FLASH0 upgraded and refurbished in the current shutdown [2], FLASH1 will be basically completely rebuilt in 2024/25.

Conceptual Overview of the Beamline

So far FLASH1/2 are plain SASE (Self-Amplified Spontaneous Emission) FELs (Free-Electron Lasers). The new FLASH1 beamline, however will be optimized for high repetition rate HGHG (High Gain Harmonic Generation) and EEHG (Echo-Enabled Harmonic Generation) external seeding [3] within the project. SASE is an extremely powerful FEL mechanism, but external seeding enhances the control over properties of the produced FEL radiation, i.p. the longitudinal coherence, substantially [3]. Seeding, i.p. EEHG, is a delicate two-stage process: The bunch, with incoming PSD (phase space distribution) Ψ_0 and reference energy E_0, is overlaid in the first undulator (modulator UM1) with the first seed laser beam (L1). Overlaid means transverse overlap for a finite distance (undulator length) ($\rightarrow x, x', y, y'$), temporal overlap, and that the energy of the seeded slice is in resonance with the laser beam L1 in undulator UM1. Then the energy modulation from L1 and UM1 is strongly over-sheared in the first magnetic chicane (**CH1**), and the bunch is overlaid in the second undulator (modulator UM2) with the second seed laser beam (L2). The conditions on overlay are just the same as in UM1. In addition the distance between the two modulation stages (M1,M2) should be as short as possible, so that the delicate over-sheared PSD from M1 is not distorted by spurious dispersion, intra-beam scattering, etc. Finally the modulated, over-sheared, and re-modulated PSD is moderately sheared in the second magnetic chicane (**CH2**) to enhance the higher order Fourier harmonics of the charge density that will seed the FEL process in the radiator. In order to make the above, highly intricate procedure operationally feasible, the beamline needs a sophisticated design and advanced high-quality hardware.

In addition FLASH1 has a long wavelength electromagnetic undulator which uses the spent e^--beam for the generation of THz radiation for highly synchronized pump-probe experiments. However, high THz pulse energy requires that a significant fraction of the bunch is concentrated in a structure smaller than the wavelength of the radiation. This is typically achieved by a spike-like longitudinal structure. The moderately compressed and highly linear seeding bunch does not such features. Hence a post-compressor chicane was designed to located downstream between FEL radiator and THz undulator. Finally the beam is vertically bent into the dump beamline capable of safely disposing of 100 kW beam power.

Here we give an overview of the FLASH1 beamline with emphasis on the “non-photon” sections, namely the collimation and matching section, the chicanes, the longitudinal diagnostics and the THz and dump beamline. The “photon-related” sections of the beamline, namely the modulators and the radiator will be described in greater detail in [5].

BEAMLINE DETAILS

The beamline is split into several functional sections as is shown in FIg. 1

The 1st collimator is located downstream of the last accelerating module. FLASH1 has a 2nd collimator close to the start of the in-coupling chicane (**InC**) in FL1MOD1. The optics has been optimized so that almost all transverse

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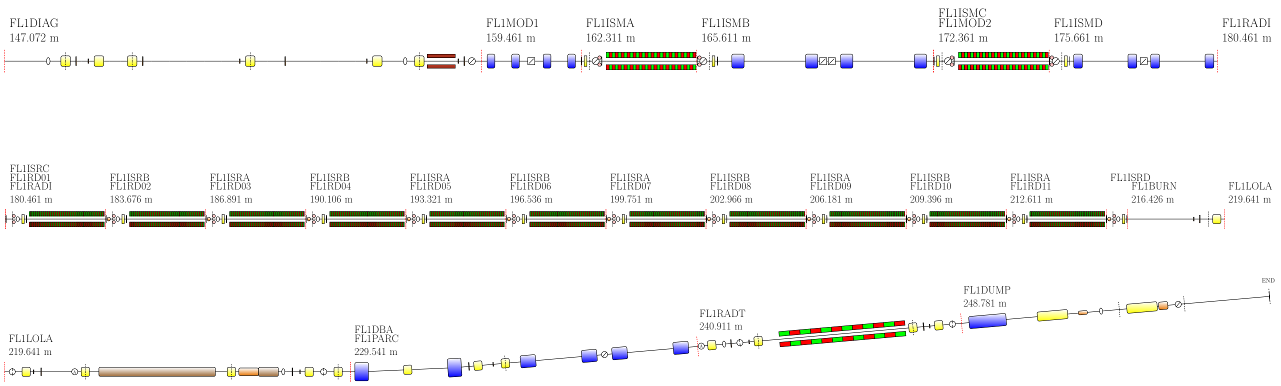

Figure 1: Schematic layout [6] of the FLASH1 beamline: top: FL1DIAG-FL1MOD2 ($\Delta s = 33.43\,\mathrm{m}$) / center: FL1RADI-FL1BURN ($\Delta s = 39.18\,\mathrm{m}$) / bottom: FL1LOLA-FL1DUMP ($\Delta s = 38.86\,\mathrm{m}$). Each line is to scale but they vary in overall length.

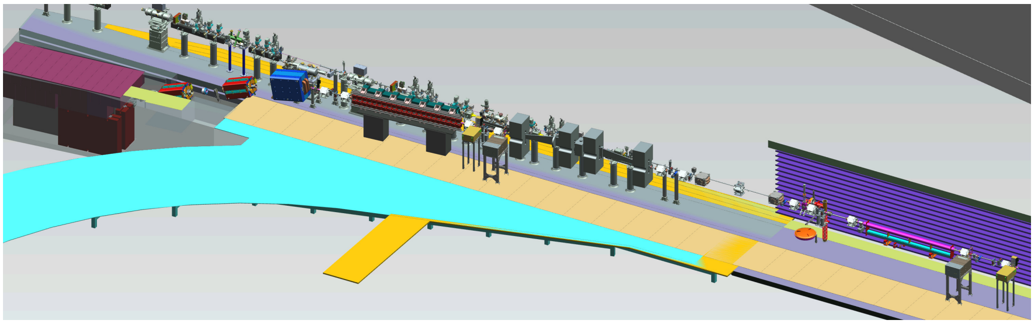

Figure 2: CAD drawing from FL1LOLA to FL1DUMP.

halo particles beyond $15\,\sigma$ will be caught. The section contains six quadrupoles, every 2nd with an embedded stripline-BPM, each 4 horizontal and vertical steerers, 2 toroids, and a screen station. The is will enable steering and re-matching the beam out of the linac into the seed modulator section independently of FLASH2.

The modulator sections FL1MOD1/2 contain the two chicanes needed for the EEHG external seeding process as briefly explained in subsection . An additional chicane **InC** is needed for in-coupling of the first seed laser. This chicane has only two operational states: active, for inserting the in-coupling mirror, and flat, for retracted mirror. The two seeding chicanes (and the post-compressor chicane **PoC**) need to be fully tunable during set up of the FEL Process. Because of the delicacy of the seeding process this requires almost perfect chicanes in the complete tuning range. All chicanes should guarantee an M_{56}-reproducibility of 1.0×10^{-3}, spurious dispersion $< 1\,\mathrm{mm}$ and an orbit-closure under tuning of $< 200\,\mu\mathrm{m}$ which is already technically challenging. Table 1 shows the minimum required beam offsets and the M_{56} tuning ranges (for inserted and retracted in/out-coupling mirrors where applicable). The large tuning ranges are challenging because they imply strong constraints on the field quality, and simultaneously large good-field regions. All magnets should comply to $|\delta B\mathrm{d}l/B\mathrm{d}l| < 5 \cdot 10^{-4}$ inside the good-field region. In addition the spacial constraints in the bounded footprint of FLASH enforce rather small magnets.S

Table 1: Chicane Specifications

chic.	**beam offset**	M_{56} **m. in**	M_{56} **m. out**
InC	≥ 7.5 mm	—	~ 0 µm
CH1	≥ 20.0 mm	400 µm - 14.5 mm	0-250 µm
CH2	≥ 7.5 mm	40-350 µm	0-300 µm
PoC	≥ 0.0 mm	—	0-75 mm

Table 2: Dipole Specifications

Bend for	**angle** **/°**	**length** **/mm**	**gap** **/mm**	**good-field** **/mm**
InC	0, 1.3-1.5	≤ 350	≥ 25	≥ 50
CH1	0, 0.4-4.0	≤ 450	≥ 25	≥ 170
CH2	0, 0.1-0.7	≤ 300	≥ 25	≥ 50
PoC	0, 1.0-8.0	≤ 500	≥ 35	≥ 320

Table 2 shows the design constraints on the chicane dipoles in the FLASH1 beamline. The sections also contain the two modulator undulators, each bordered by two 0.6 m long intersections equipped with a beam position monitor (BPM), a quadrupole with x/y-mover, a screen station, 2 beam loss monitors (BLMs) and x/y-steering using air-coils or small ferrite coils.

The radiator undulator section consists of eleven APPLE-III-type undulator segments bordered by twelve 0.6 m long intersections all together with a BPM, a phase shifter, a quadrupole with x/y-mover, a wire scanner station, 2 BLMs, and steering using air-coils or small ferrite coils. Downstream of the 11 seed radiators space is foreseen for a 3rd harmonic afterburner which will, however, not be installed in the 2024/25 shutdown.

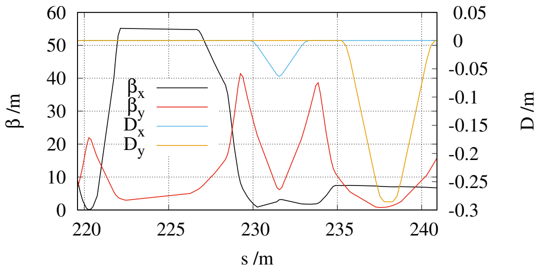

Figure 3: Optics: FL1LOLA to FL1PARC.

Figure 2 shows a 3D-CAD drawing of the FLASH1 beamline downstream of the undulator. The transverse deflecting structure LOLA already in use in the current FLASH1 beamline will be moved downstream of the radiators. For this the wave-guides have be extended so that the S-band modulator and klystron can stay in their old place at the price of a higher RF attenuation. LOLA [7] will be installed to streak horizontally so that the vertical dispersion of the post compressor chicane, about 0.3 m at full angle, serves as an energy spectrometer perpendicular to the streak plane. The optics, shown in Fig. 3 has been optimized to achieve resolutions of about $\delta_\tau \approx 20\,\text{fs}$, $\delta_E \approx 100\,\text{keV}$, depending on the attainable streak angle.

In order to early-on separate the e^--beam from the FEL photon beam, a 5° quasi-DBA using standard FLASH chicane dipoles has been designed. By simple algebra one can show that the geometric M_{56} of a symmetric double bend arc vanishes iff the transverse dispersion is matched. The absolute small, negative longitudinal dispersion of the two dipoles themselves is retained so that this extremely simple structure is only a quasi-DBA.

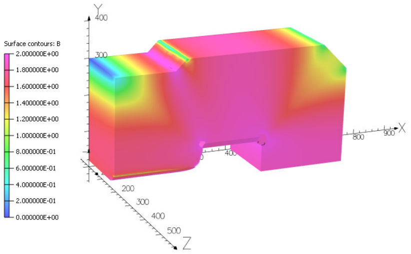

Figure 4: Field-map of a quarter of the proof of principle candidate for chicane dipole for **PoC** (by courtesy of Alexander Aloev (DESY-MEA)).

Downstream of the horizontal quasi-DBA will be the vertical post compressor C-chicane **PoC**. The compression $C := (1 + hM_{56})^{-1}$ with longitudinal dispersion M_{56} and the (negative) bunch chirp $h := d\langle E(\tau)\rangle_\perp/d\tau$ depends on the product of chirp and dispersion. Since the typical chirp of a bunch optimized for HGHG/EEHG seeding is presumably small, a relatively large, fully tunable M_{56} was chosen for the design. The specifications of the chicane and its dipoles can be found in Tables 1 and 2. The dipole specifications are extremely challenging. Therefore a numeric feasibility study was performed on the magnet by the DESY magnet design group. Figure 4 shows a field map of a quarter-dipole. Despite the locally high Field (up to 2 T) and the unavoidable saturation effects the magnet fulfills the field quality and good-field constraints sufficiently well to be a candidate for production. The **PoC** chicane also serves as energy spectrometer for the LOLA diagnostics. A screen/cameras system which allows high resolution imaging for a large variety of chicane deflection angles is currently being designed.

The post compressed bunches with enhanced peak current and some nonlinear spiky shape will enhance the THz pulse energies from the THz undulator — at the price of a reduced synchronicity of FEL and THz pulses due to the M_{56} of the post compressor. As a side effect, of the earlier separation of the electron beam from the FEL photon beam, the THz beam from the moved undulator is also better separated from the FEL, so that THz and FEL diagnostics can easier be disentangled.

In the new design the dump was relocated to generate more space in the beamline to enable post-compression of the electron beam for THz generation, to early-on separate photons from electrons for generating more space for the photon diagnostics, and to mitigate the radiation dose from the dumpline at the photon electronics. Downstream of the THz undulator a vertical bending magnet sends the e^--beam into the dump pit and separates the electrons from the THz beamline. This improves operability of the new dumpline because the transverse geometric coupling, inherent in the old design due to a tilted dipole, was removed by disentangling the geometry via the use of dedicated horizontal and vertical dipoles.

The beamline designed for FLASH1 is finished and the component design is close to finalization. We are looking forward to installing the new beamline in the 2024/35 shutdown.

ACKNOWLEDGMENTS

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