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FLASH UPGRADE FOR SEEDING *

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Abstract

An upgrade for FLASH, the SASE FEL in Hamburg, is planned after 2020 aiming at fulfilling user requirements like fully coherent, variable polarization, and multi-colour pulses. In this proceeding, we focus on the FLASH1 beamline that will be operated in seeded mode at a high repetition rate. In particular, we will present and discuss the proposed seeding schemes for delivering FEL radiation with wavelengths from 60 down to 4 nm.

INTRODUCTION

FLASH is the free-electron laser in DESY, Hamburg [1]. It has three beamlines: FLASH1, FLASH2 and FLASH-Forward, and the maximum number of bunches per second for user experiments is 5000 shared amongst the beamlines thanks to the long flat top of the RF-Voltages enabled by the TESLA cavities. The various beamlines can share the produced bunches, in fact, simultaneous operation between FLASH1 and either FLASH2 or FLASHForward is possible [2] thanks to a kicker septum placed in front of the FLASH2 beamline. Also, seeding techniques are studied at sFLASH that is placed upstream of the FLASH1 undulator. The current status of the sFLASH project is discussed in [3]. At the moment the HGHG seeded radiation is operated at 10 Hz, which corresponds to the repetition rate of the current seed laser so that the potential of FLASH is only partially exploited. In addition, the radiation is not accessible by the users of the FLASH1 experimental hall. But, using the FLASH1 undulator as radiator for seeding is not a solution, because the transport of the bunched electron beam from the second sFLASH chicane to the undulator is challenging and saturation is reached before the end of the undulator [4]. The foreseen FLASH upgrade [5] is going to dedicate FLASH1 as a seeding beamline for user delivery at wavelengths spanning from 60 down to 4 nm and increase the repetition rate for seeding operation to 100 kHz in a first stage, and then to 1 MHz by the implementation of an innovative seed laser scheme.

In this contribution, the main details of the seeding upgrade and preliminary start-to-end simulation results are presented.

FLASH UPGRADE OVERVIEW

The upgrade plans of the FLASH facility are described in Ref. [5]. It includes a laser heater, an energy increase from 1.25 to 1.35 GeV and a redesign of the bunch compressors [6]. A modification of FLASH2 is planned to allow for more advanced FEL schemes like multi-colour and attosecond pulses [7]. As mentioned in the introduction, FLASH1 will be devoted to seeding, delivering FEL radiation with a wavelengths between 60 and 4 nm. Figure 1 shows a scheme of the designed FLASH1 beamline. It consists of two modulators and one radiator, the first modulator is followed by a magnetic chicane with maximum longitudinal dispersion of 25 mm, enabling EEHG operation at the n=-1 working point even at the shortest wavelength (4 nm). A second chicane is installed before the radiator, with a foreseen maximum dispersion of 300 µm and it will be used as bunching chicane for both EEHG and HGHG. The current FLASH1 fixed gap undulators are going to be replaced by variable gap helical undulators. The detailed undulator parameter are going to be presented in the next section. So far, fixed gap undulators in FLASH1 has limited FLASH2 operation, as for every wavelength change it is also necessary to change the electron beam energy. With this upgrade, the machine will be operated at two fixed electron beam energies: 750 MeV and 1.35 GeV to reach all design wavelengths. This will significantly ease wavelength changes. Three seed laser options are under study for FLASH1: two are in the ultra-violet (UV) range and one in the visible in the range 413-480 nm. The UV seed laser in one case is the result of a cascaded process with final wavelength range 294-327 nm, in the other case it is the third harmonic of the seed source resulting in the range 230-300 nm, but it has a much lower energy. For this reason, in this and previous studies (see [8]) only the VIS option and the UV option in the range 294-327 nm are studied.

UNDULATOR PARAMETERS AND TUNABILITY

The undulators foreseen for the radiator section are APPLE III type with variable polarization and gap (with minimum gap 8 mm). The undulator has a period λ_u of 33 mm, and a total length of 2.5 m. This undulator enables wavelengths from 60 to 20 nm within the e-beam energy of 750 MeV and wavelengths from 20 to 4 nm at 1.35 GeV.

For the external seeding schemes, also seed laser tunability should be considered. The UV seed laser gives a continuous tunability starting from FEL wavelengths of 36.4 nm and shorter, but for longer wavelengths there are gaps as shown in fig. 2. While the VIS seed gives a continuous tunability for the whole FEL wavelength range of interest. Up to the 12^{th} harmonic FEL radiation will be generated using the HGHG scheme by enabling only one of the two modulators and seed lasers. In fact, this harmonic is the lowest one rou-

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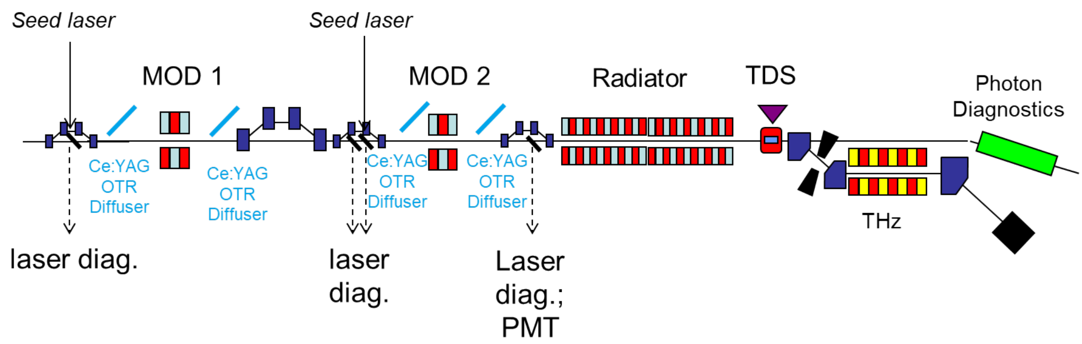

Figure 1: Proposed FLASH1 seeding beamline and fundamental diagnostics.

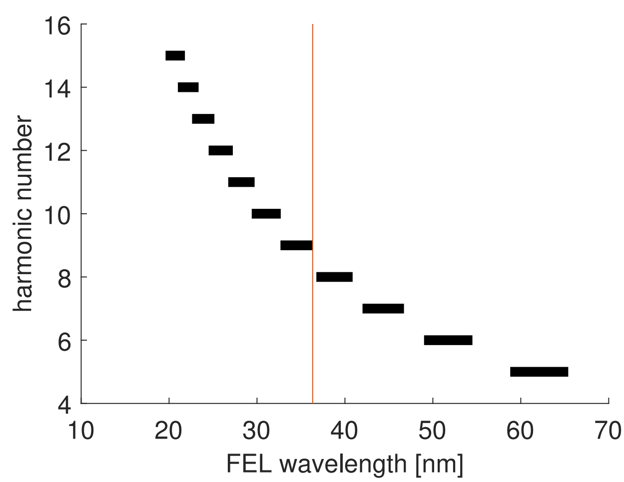

Figure 2: Tunability of the seeded FEL for the seed laser wavelength tuning range 294 – 327 nm and an e-beam energy of 750 MeV. For wavelengths shorter than 36.4 nm (left side of the red line), continuous, gap-free tunability is achieved.

tinely produced at FERMI [9] in the FEL1 beamline. EEHG scheme will be applied to enable shorter wavelengths down to 4 nm. This scheme has been recently successfully shown at FERMI [10].

Modulator Parameters

The modulator is planar and will have an undulator period λ_u of 82.6 mm, the length considered so far is 2.478 m. The minimum gap will depend on the seed laser type (UV or VIS) that will be chosen. Knowing the seed laser wavelengths, it is possible to estimate the needed undulator strengths and thus gaps needed in the two cases: UV seed and VIS seed. In table 1 the calculated gaps for the e-beam energy E_0 of 1.35 GeV, where the gaps are smaller, are given. For the UV case the minimum gap is larger compared to the VIS case. These gap values should not be a limitation for the diameter of the vacuum pipe.

Table 1: Gaps needed for the different seed laser and electron beam energies options.

seed type	E_0	gap
UV	1.35 GeV	18-19 mm
VIS	1.35 GeV	14-15 mm

SIMULATION RESULTS

FEL simulations were performed using GENESIS 4 [11]. The advantage in using this code is that the particles are not constrained in one slice for all the simulation, but they can move freely from one slice to another consecutive one. This aspect is essential for the EEHG where the first chicane has usually high dispersion, thus the longitudinal particle displacement exceeds several slices. Initial tolerance studies on the seed lasers for the two different seed laser options UV and VIS have been presented for the most challenging FEL target wavelength 4 nm in [8] and are compared with the theory estimation given in [12]. At the moment, CSR studies for these two options are under investigation. The recently achieved results with a start-to-end (S2E) simulation are presented and they are compared with simulation results obtained using an ideal gaussian beam defined with the same parameters presented in table 2. For the S2E simulation, a particle distribution file from ELEGANT [13] is dumped before the first modulator of the seeding beamline. The beam used for the FEL simulation has been described in [6], for which space charge (SC), incoherent (ISR) and coherent synchrotron radiation (CSR) effects are taken into consideration. The main beam properties are summarised in table 2. Once the sdds distribution file from ELEGANT is converted in hdf5 format, it is possible to load it to GENESIS 4 and track it along the seeding beamline using the "one for one" simulation mode. For this initial test, a UV seed laser at 300 nm is used, and the radiator is tuned to the thirty-second harmonic of the seed laser. The parameters for EEHG has been decided by maximising the Stupakov bunching formula [14].

Table 2: Main parameters of the beam simulated in [6]. I_{peak} shows the peak current, and $\epsilon_{p,(x,y)}$ are the transverse projected emittances.

E_0	σ_E	I_{peak}	charge	$\epsilon_{p,x}$	$\epsilon_{p,y}$
1.35 GeV	75 keV	500 A	250 pC	0.5 µm	0.4 µm

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Table 3: Parameters for EEHG seeding. The harmonic number is given by the sum of n and m, $A_{1,2} = \Delta E_{1,2}/\sigma_E$, where ΔE is the energy modulation transferred from the seed laser to the electron beam and σ_E is the energy spread of the electron beam. $R_{56}^{(1),(2)}$ is the dispersion strength of the chicane, where $^{(1)}$ and $^{(2)}$ indicate respectively the first and the second chicane.

harmonic	n	m	A_1	A_2	$R_{56}^{(1)}$	$R_{56}^{(2)}$
32	-1	33	4.6	5.3	5.974 mm	185 µm

Table 3 shows the main EEHG parameters used for the simulation. The expected FEL saturation power is derived with the Ming-Xie formulas, adapted for pre-bunched beam [15] using the parameters presented in Table 2. The FEL saturation power results to be 1.13 GW and it is achieved after 9.9 m of undulator active length. The Pierce parameter is calculated to be 0.0017 and the gain length 1.12 m. So, with the radiator described in the previous section, we expect to achieve FEL saturation after four undulator modules.
The result without including ISR and CSR in the seeding section are shown in figs. 3 to 5. In these figures "S2E beam" represents the simulation done using the beam coming from the ELEGANT simulation and "ideal beam" the simulation done using an ideal beam.

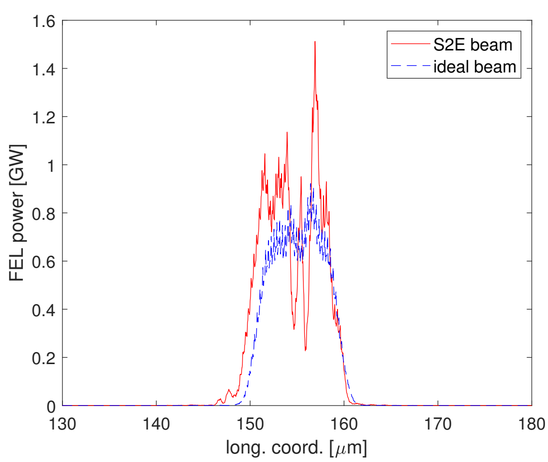

Figure 3: FEL power profile after 10 meters from the start of the radiator section.

FEL power at 10 m achieves the estimated saturation value and fluctuations could be associated to the statistics of the simulations. The spectra are shown in fig. 5. They are compatible except a tiny peak on the left of the main peak of the S2E beam, that might come from the e-beam imperfections.

CONCLUSION AND OUTLOOK

The envisioned FLASH1 beamline for the FLASH2020+ upgrade has been presented. The FEL performance has been introduced using a beam coming from linac simulations where SC, CSR and ISR has been included, showing that

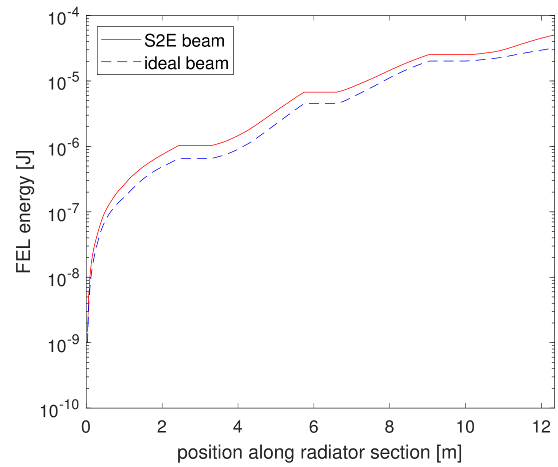

Figure 4: FEL gain curve along the radiator in logarithmic scale, both maximum and mean FEL power are shown.

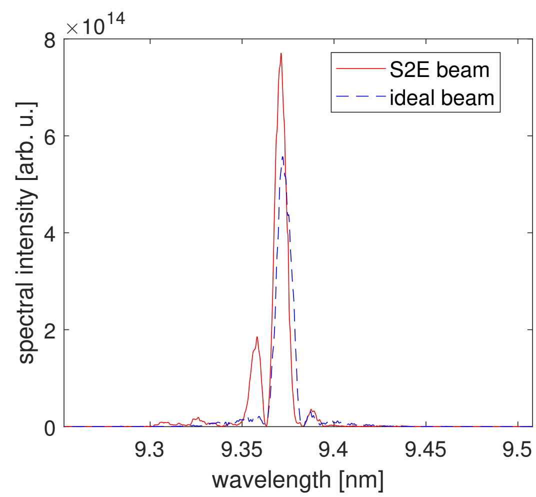

Figure 5: FEL spectrum profile after 10 meters from the start of the radiator section.

with a realistic beam it is possible to radiate seeded radiation. Next step will be to improve the quality of the radiation pulse obtained in terms of longitudinal coherence. Also, studies on the wakefield effects in the radiator section to evaluate the optimal vacuum system that preserves the EEHG process are planned. Furthermore, there are ongoing studies to characterise the impact of CSR effects from the two EEHG chicanes.

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