HGHG SCHEME FOR FLASH II

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Abstract

FLASH II is a major extension of the existing FLASH facility at DESY. It has been proposed in collaboration with the Helmholtz-Zentrum Berlin(HZB). FLASH II is a seeded FEL in the parameter range of FLASH. The final layout of the undulator section of FLASH II allows for different seeding schemes. So that seeding with an HHG source as well as seeding in cascaded HGHG scheme and several combination of these schemes are possible.

However, for the shortest wavelengths down to 4 nm the cascaded HGHG scheme is considered. It consists of two frequency up conversion stages utilizing a Ti:Sa laser based seeding source in deep UV range. We present and discuss start-to-end simulation studies for the shortest wavelength generated in the HGHG cascade of FLASH II.

INTRODUCTION

FLASH, the free-electron laser at DESY, has been a user facility since 2005, delivering radiation in the wavelength range from 4.1 nm to 45 nm with pulse trains from 40 kHz to 1 MHz in single or multi bunch mode up to 500 bunches with 100 ms (10 Hz) intervals [1, 2, 3].

In order to improve the radiation properties and increase the beam time delivered to the users, an extension of FLASH called FLASH II has been proposed by DESY in collaboration with the HZB [4]. FLASH II is planned as a seeded FEL, in the sense that in addition to SASE radiation deliverable over the parameter range of FLASH, several seeding schemes incorporated in the layout allow for the production of seeded and in a later stage polarized FEL radiation.

Making use of the existing accelerator, FLASH II is basically a second undulator beamline built in a separate tunnel. To feed FLASH II with electron beam, parts of the FLASH bunch trains are separated from the main beamline into the new undulator beamline with a shallow angle. In contrast to the existing FLASH facility, all FLASH II undulators will have a variable gap relaxing the dependency of the wavelength on the beam energy thus allowing for an independent operation of the FLASH and FLASH II.

The final layout of the FLASH II undulator section allows for seeding with an HHG source, seeding in a cascaded HGHG scheme [5], and also several combinations of these schemes. For the shortest wavelengths down to 4 nm the cascaded HGHG scheme is considered. We present and discuss start-to-end simulation studies for the shortest wavelength generated in the HGHG cascade of FLASH II.

The time dependent mode of the code GENESIS [6] has been used for the presented simulations of the HGHG section. The optimisation of the FLASH II extraction section and the start-to-end simulation of the electron bunch are detailed in [7].

HGHG LAYOUT AND NOMINAL ELECTRON BEAM

The schematic view of the planned facility including FLASH II is shown in Fig. 1. Behind the last accelerating module, the beam is switched between the present FLASH facility and the new FLASH II undulator line. The new FLASH II tunnel houses the electron beamline consisting of a matching and diagnostic part, the seeding-undulator section, and the SASE-undulator section. Indeed, the seeding section is reserved for the cascaded HGHG undulators, but the SASE undulator will serve as the final radiator for the HGHG scheme and also as an amplifier for a direct seeding with an HHG source. The design, in particular the period length, of the final amplifier has to be a compromise between minimum achievable wavelength and tunability for simultaneous operation of FLASH and FLASH II. This has a major impact on the performance of the HGHG line, as the period length of the final amplifier is longer than optimum value for the shortest wavelength of 4 nm, reducing the corresponding K-value.

Table 1 shows the nominal electron beam parameters expected for FLASH II. They are similar to those for FLASH with the exception of the energy spread, which grows due to coherent synchrotron radiation in the extraction area.

Table 1: Nominal Electron Beam Parameters for FLASH II

Electron Beam Parameters	
Energy Range	0.5 - 1.25 GeV
Peak Current	2.5 kA
Normalized Emittance	1.4 mm mrad
Energy Spread	0.5 MeV
Rep. rate	10 Hz
Bunch separation	1 - 25 μs

The planned cascaded HGHG FEL consists of two frequency up-conversion stages, see Fig 2, each composed of a modulator, a chicane, and a radiator. The first modulator has a period length of 8 cm and a length of 0.8 m. The following radiator with a period length of 4.1 cm consists of 2 helical undulator modules each 3 m long. The second modulator consists of a module of the same type as the previous radiator. It follows the fresh-bunch chicane [8] between the first and second stage. As mentioned before, the SASE undulator line acts as the final radiator for the

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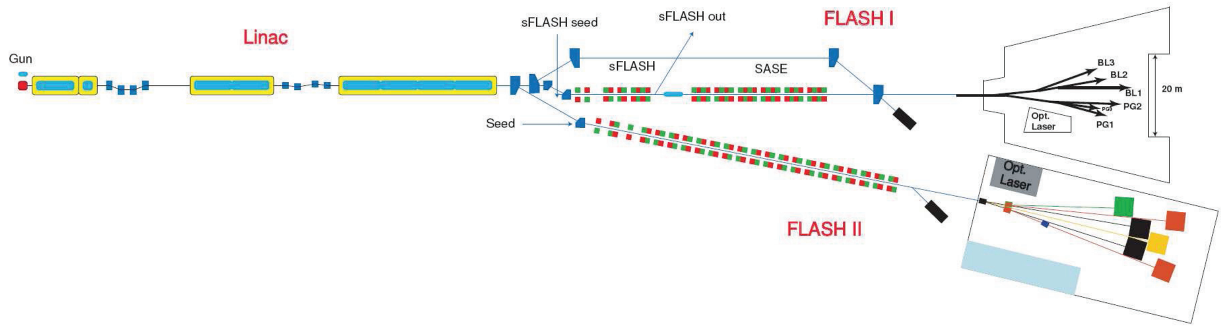

Figure 1: Schematic layout of the planned FLASH facility. Behind the last accelerating module, the beam is switched between FLASH I, which is the present undulator line, and FLASH II, which is the upgrade. Behind the extraction point, space is reserved for an additional laser system for seeding.

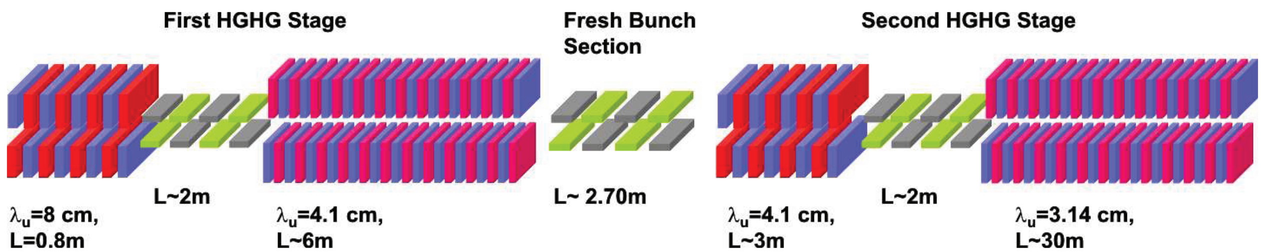

Figure 2: The cascaded HGHG consists of two frequency up-conversion stages.

HGHG scheme. It consists of 12 modules each 2.5 m long with a period length of 3.14 cm. The envisaged seed laser is a Ti:Sa laser at a repetition rate of 100 kHz, which is under development at DESY [9]. After frequency up-conversion, the seeding wavelength ranges from 200 nm up to 270 nm.

START-TO-END SIMULATIONS

For the presented simulation studies, an electron beam distribution resulting from the start-to-end simulations of accelerator line has been used. These simulations track the particles from the injector through the FLASH accelerator and FLASH II extraction to the entrance of the HGHG section. Figure 3 shows the properties of the simulated electron bunch. As a comparison with Tab. 1 shows, there is a reasonable agreement between the simulated beam paremeters and the nominal values. Note that the FLASH II extraction section is not finalized yet. It is still subject to ongoing optimisations [7]. Therefore, the properties of the electron distribution might change.

In spite of the good general agreement between the simulated and nominal electron beam parameters, the simulated performance of the HGHG section differ strongly for these two cases. For example, a much higher seeding power is necessary to generate the same bunching on higher harmonics in the case of the simulated beam. Furthermore, the same bunching and uncorrelated energy spread do not result in the same or even comparable amount of radiation power. A careful examination of the beam properties and the FEL process uncovers the problem. The chirp of the mean energy along the bunch needed for compression prevents effectively both generation of the bunching and the coherent emission in the radiator, as is quantified below.

Even for a short section of the bunch of 10 μm length – corresponds to a seed pulse of 33 fs – the total correlated energy change amounts to $\Delta\gamma = 2.5$, see Fig. 3. This is almost a factor of 3 higher than the initial uncorrelated energy spread. The corresponding high total energy deviation deteriorates the frequency up-conversion process in in both HGHG stages. Therefore, the usage of the fifth and seventh harmonics in both stages for 8 nm and 4 nm as were planned previously [4] has to be reconsidered. Furthermore, a more elaborated modulator scheme [10] allowing for very high harmonics in the HGHG stages is not suitable any more as it is extremely sensitive to the correlated energy deviation [11].

However, further studies show that an increase of the seeding power in combination with a readjustment of the allowed maximum harmonic numbers result in GWs of output power for wavelengths up to 7.5 nm. An example is shown in Fig. 4. For this simulation the seeding radiation has a wavelength of 240 nm, a pulse duration of 30 fs and a peak power of 3.6 GW. The first stage is adjusted to the 8th harmonic while the second stage is adjusted to the 4th.

As the more elaborated modulator schemes are not ben-

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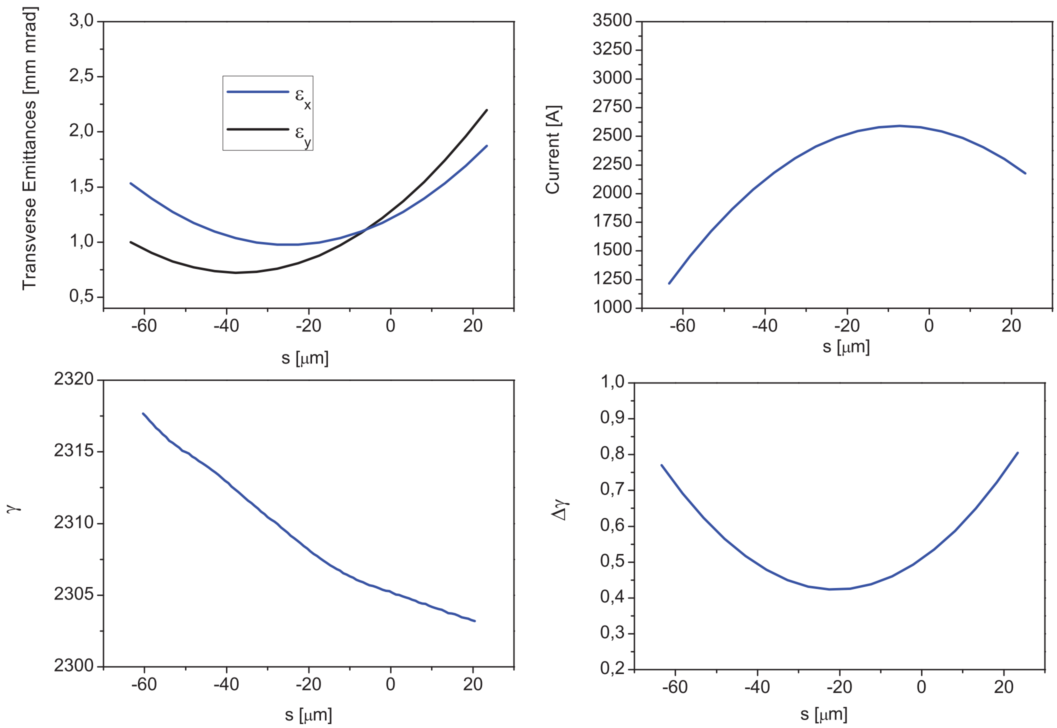

Figure 3: The properties of the electron bunch used for the presented FEL simulations. The normalized transverse emittances (top left), current profile (top right), mean beam energy (bottom left), and uncorrelated energy spread (bottom right) as functions of the position along the bunch are shown.

eficial for beams with very high energy deviation, there are basically three possibilities to down-convert the seeding wavelength to the target wavelength of 4 nm. One can reduce the seeding wavelength as far as possible, or increase the total harmonic numbers, or introduce an additional frequency up-conversion in the final radiator by changing the K-values of the variable gap modules accordingly. Figure 5 shows the simulated performances for these possibilities.

Assuming that the tunability of the output radiation and thus of the seeding wavelength is mandatory, the shortest available seeding wavelength is around 200 nm. Accepting a maximum harmonic number of 8 in the first stage, the second stage has to be adjusted to 6^{th} harmonics, so that a final output wavelength of 4.2 nm can be targeted,as shown by the blue curves in Fig. 5. Using a seed with a wavelength of 240 nm and 8^{th} harmonics in the first stage, the second stage has to be adjusted to 7^{th} harmonics, so that a final output wavelength of 4.3 nm can be targeted, as shown by the red curves in the Fig. 5. The generated bunching at the entrance of the final radiator is in both cases around 2%, shown by the blue and red curves in the Fig. 5a. Although this value is not very high, it is sufficient to generate output peak powers of 20 MW to 30 MW for a beam with nominal parameters. As shown in Fig. 5, there is a reduction of peak power and a strong degradation of the spectral quality in the case of the simulated bunch.

Adjusting the HGHG-stages for 7.5 nm output wavelength, there is a bunching of about 5% on the second harmonics after 15 m in the final amplifier, as shown by the black curve in the Fig. 5a. A readjustments of the K-value of the remaining undulators allow us to obtain radiation with a wavelengths of 3.75 nm which saturates after further 6 m, as shown by the black curves in Fig. 5. In this case, the generated pulse is shorter but it has similiar peak power and spectral properties.

CONCLUSION

FLASH II is an extension of the existing FLASH facility. The final layout of the undulator section of FLASH II incorporates the option for different seeding schemes. So that seeding with an HHG source as well as seeding in cascaded HGHG scheme and several combination of these schemes are possible. We present and discuss start-to-end simulation studies for the shortest wavelength generated in the HGHG cascade of FLASH II. In spite of the good general agreement between the simulated and nominal electron beam parameters, a careful examination of the beam properties and the FEL process uncovers that the energy chirp

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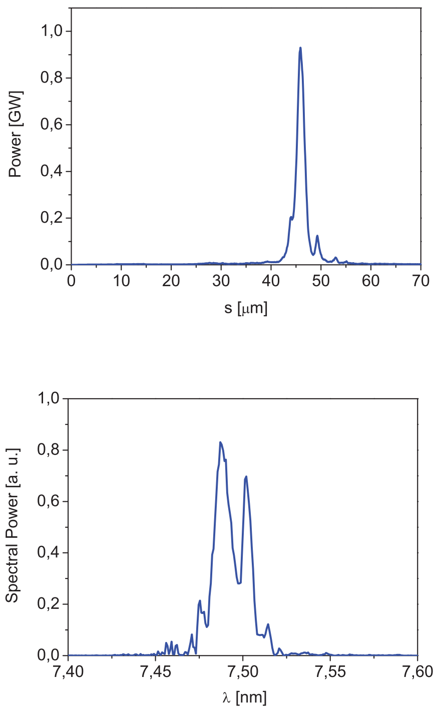

Figure 4: Temporal (top) and spectral (bottom) profiles of the output of the HGHG-FEL. The Saturation is achieved after 20 m.

needed for compression prevents effectively the generation of high quality radiation at short wavelengths around 4 nm. As the optimisation for FLASH II are not finalized, we hope that further optimisations can provide a beam with less energy chirp.

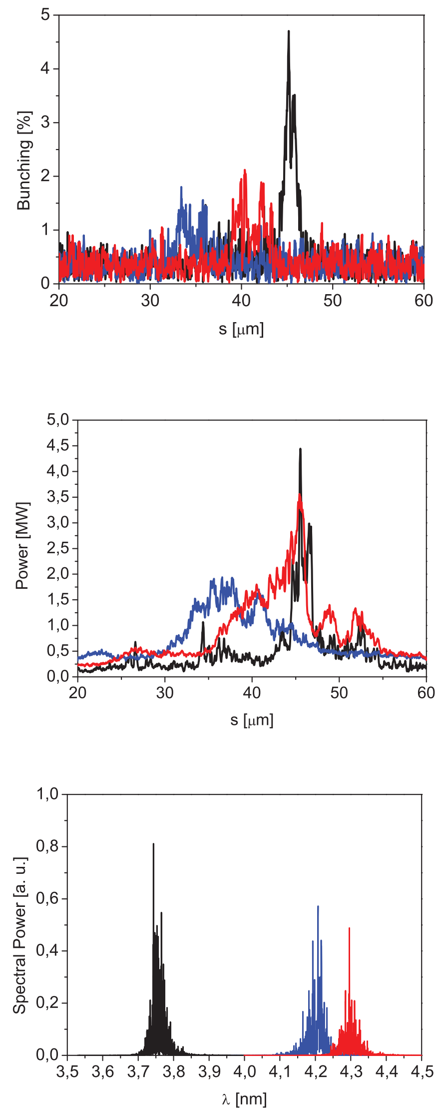

Figure 5: a) Bunching on the target wavelength (top), b) temporal (middle) and c) spectral (bottom) profiles of the HGHG-output after 20 m in the final radiator. The blue curves show results of simulations starting with a 200 nm seed and using a total harmonic number of 48. The red curves are results of simulations starting with 240 nm seed and utilizing the 56th harmonics. The black curves are results of simulations optimized for 7.5 nm using a frequency up-conversion in the final amplifier.

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