CONCEPT FOR A SEEDED FEL AT FLASH2*

C. Lechner†, R. W. Assmann, J. Bödewadt, M. Dohlus, N. Ekanayake‡, B. Faatz, G. Feng, I. Hartl, T. Laarmann, T. Lang, L. Winkelmann, I. Zagorodnov, DESY, 22607 Hamburg, Germany
S. Khan, DELTA, TU Dortmund University, 44227 Dortmund, Germany
A. Azima, M. Drescher, Th. Maltezopoulos§, T. Plath,
J. Rossbach, W. Wurth, University of Hamburg, 22671 Hamburg, Germany

Abstract

The free-electron laser (FEL) FLASH is a user facility delivering photon pulses down to 4 nm wavelength. Recently, the second FEL undulator beamline 'FLASH2' was added to the facility. Operating in self-amplified spontaneous emission (SASE) mode, the exponential amplification process is initiated by shot noise of the electron bunch, resulting in photon pulses of limited temporal coherence. In seeded FELs, the FEL process is initiated by coherent seed radiation, improving the longitudinal coherence of the generated photon pulses. The conceptual design of a possible seeding option for the FLASH2 beamline foresees the installation of the hardware needed for high-gain harmonic generation (HGHG) seeding upstream of the already existing undulator system. In this contribution, we present the beamline design and numerical simulations of the seeded FEL.

INTRODUCTION

The free electron-laser (FEL) FLASH [1] at DESY in Hamburg (see Fig. 1) has been an FEL user facility since 2005 [2], delivering high-brilliance SASE FEL radiation at wavelengths down to 4.2 nm. A superconducting linear accelerator generates high-quality electron bunches with energies of up to 1.25 GeV in bursts of up to 800 electron bunches at 1 MHz repetition rate with 10 bursts per second. These so-called "macro-pulses" are distributed over two undulator beamlines using vertical flat-top kickers. This enables a full 10-Hz macropulse repetition rate in both beamlines, the FLASH1 beamline with a fixed-gap undulator, where also the seeding experiment sFLASH [3] is installed, and the recently added FLASH2 beamline. Simultaneous SASE FEL delivery to photon user experiments at both FLASH1 and FLASH2 is now routinely achieved [4,5]. Moreover, during a machine study beamtime, simultaneous three-beamline SASE (FLASH1, FLASH2, and sFLASH) was demonstrated [6].

In SASE mode of operation, the exponential amplification process in the high-gain FEL is initiated by spontaneous undulator radiation emitted by the electron bunch at the beginning of the undulator. The longitudinal coherence of the FEL radiation delivered in this mode is typically poor.

* Work supported by Federal Ministry of Education and Research of Germany under contract No. 05K13GU4, 05K13PE3, and 05K16PEA.
† christoph.lechner@desy.de
‡ present address: Michigan State University, East Lansing, MI 48824, USA
§ present address: European XFEL GmbH, 22869 Schenefeld, Germany

Table 1: Parameters for HGHG Seeding at FLASH2 (for Operation at the 14th Harmonic)

Parameter	Value
electron beam energy	1000 MeV
rms slice energy spread	150 keV
seed laser wavelength	267 nm
seed pulse energy	50 μJ
seed pulse duration	50 fs
harmonic number	14
FEL wavelength	19.0 nm
repetition rate (Phase 1A)	10 Hz
repetition rate (Phase 1B)	up to 800 Hz

The seeding technique "high-gain harmonic generation" (HGHG) [7] uses an external, longitudinally coherent light pulse to manipulate the electron beam, generating a periodic pattern of microbunches. The harmonic contents of this density modulation initiates longitudinally coherent FEL emission at the harmonic of interest.

In the conceptual planning phase of the FLASH2 upgrade, a first study to implement cascaded HGHG seeding was conducted in 2011 [8], however, this scheme was not implemented. The proposed FLASH2 seeding project described in the present paper is organized into three phases: In Phase 1A, one electron bunch per macropulse is seeded, which corresponds to a 10 Hz repetition rate of seeded photon pulses. An upgrade to a high-repetition-rate (100 kHz burst rate) seed laser system adapted to the pulse structure of the superconducting accelerator would mark the transition to Phase 1B. Delivering up to 800 seeded FEL pulses per second, this Phase combines the benefits of external seeding and of a superconducting linear accelerator. In Phase 1A/1B, HGHG seeding at the maximum harmonic of 14 will deliver seeded FEL pulses at wavelengths down to 19 nm. The parameters of this operating point are compiled in Table 1. Finally, Phase 2 foresees the implementation of the seeding technique "echo-enabled harmonic generation" (EEHG) [9], enabling seeding at shorter wavelengths. See Ref. [10] for an overview of potential FLASH2 seeding options.

PROPOSED IMPLEMENTATION OF HGHG SEEDING AT FLASH2

At the moment, the FEL beamline FLASH2 is operated as SASE FEL using a variable-gap undulator system comprising 12 modules with 2.5 m magnetic length, each. An

ISBN 978-3-95450-182-3

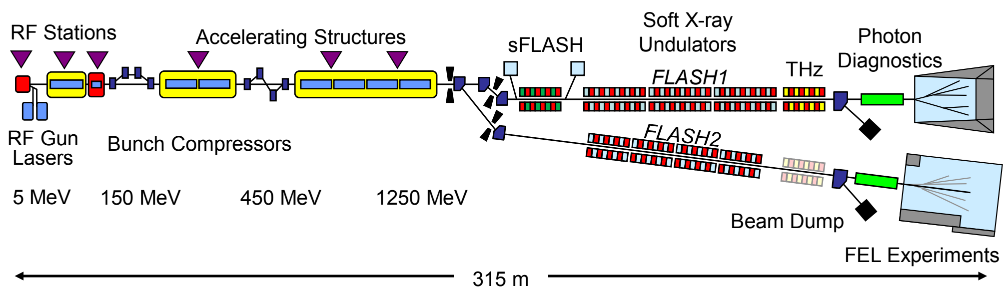

Figure 1: Layout of the FEL user facility FLASH. The superconducting linear accelerator delivers high-repetition-rate bursts of electron bunches. Vertical flat-top kickers in the switchyard at the end of the linear accelerator enable full 10-Hz macropulse repetition rate in both FEL beamlines.

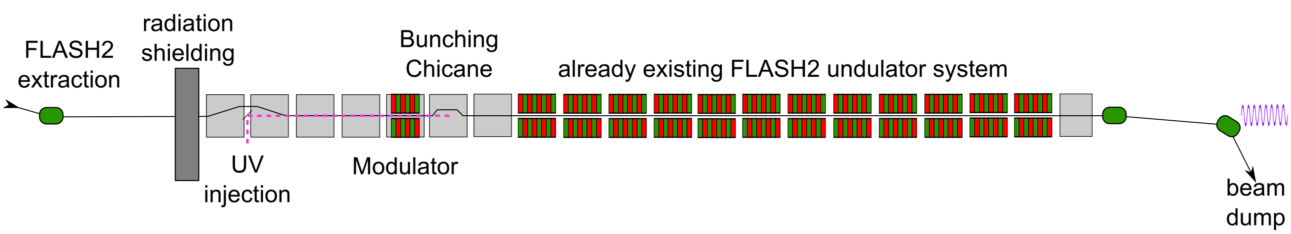

Figure 2: Modifications of the FLASH2 beamline for the implementation of HGHG seeding. Already installed is the variable-gap undulator system for SASE FEL operation down to 4 nm. In front of this undulator, approximately 20 meter of beamline are currently partly used for electron beam diagnostics, leaving room for the installation of the additional hardware required for the proposed implementation of seeding. For the implementation of HGHG seeding, a chicane guiding the electron beam around the seed laser injection mirror, a variable-gap modulator, and a bunching chicane are required. Not shown is the dedicated seed laser system and the optical transport beamline for the seed radiation.

approximately 20-meter long section in front of this undulator is currently partly used for electron beam diagnostics, leaving sufficient room for the installation of the additional hardware required for the proposed implementation of seeding at FLASH2 (see also the illustration in Fig. 2).

A first 4-dipole chicane guides the electron beam around the mirror used to inject the ultraviolet seed laser pulses onto the electron beam axis. In the modulator, these seed laser pulses interact with the electron beam, generating a periodic sinusoidal energy modulation. The proposed variable-gap modulator (maximum magnetic field 1.5 T at minimum gap 9 mm, period length 75 mm, 32 periods) enables efficient laser-electron interaction. This design meets the demanding UV seed pulse energy constraints of high-repetition-rate seeded operation (100 kHz burst rate) which is foreseen for Phase 1B HGHG seeding. Directly at the exit of the modulator, the second 4-dipole chicane used to generate the longitudinal density modulation will be installed.

This chicane is then directly followed by the FLASH2 variable-gap undulator, which is used as radiator of the HGHG-seeded FEL. A central requirement for any FLASH2 beamline modification is that the capability of FLASH2 SASE delivery at wavelengths down to 4 nm is not compromised. In particular, this rules out modifications to the already existing variable-gap undulator system.

The proposed beamline layout already reserves room for future upgrades to the advanced seeding scheme EEHG.

Seed Laser System

The proposed concept foresees the installation of a dedicated seed laser system. To generate seeded FEL radiation with continuously tunable wavelength, the seed source needs to be tunable between 260 nm and 320 nm. For a seed pulse duration of 50 fs, the required energy of the seed pulses at the laser system is 50 µJ (12 µJ at the modulator). While systems with these parameters are commercially available at 10 Hz repetition rate (for Phase 1A), the implementation of Phase 1B HGHG seeding is based on the delivery of seed pulses at a 100-kHz burst repetition rate. These very challenging parameters require a research and development effort to design and produce a seed laser system meeting the demands.

In-vacuum transport of the seed radiation from the laser system to the modulator is proposed to avoid air turbulence-related beam fluctuations and to shield the optics against chemical substances.

FEL Diagnostics

To characterize the seeded FEL radiation, the photon diagnostics infrastructure of the FEL beamline FLASH2 will be used. This includes measurements of the photon pulse energy, the spectrum, the temporal profile (with THz streaking), and the temporal coherence.

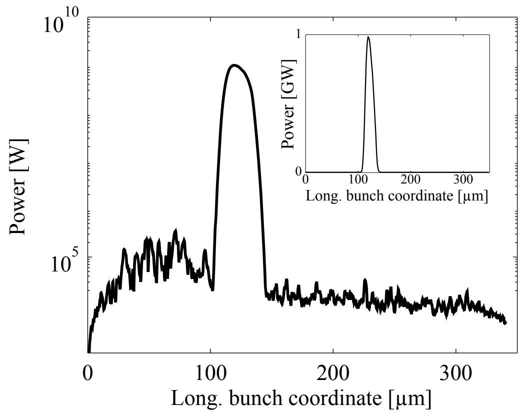

Figure 3: Temporal power profile after three modules of the radiator.

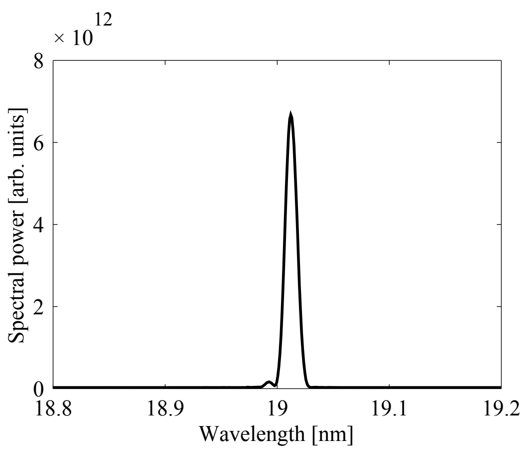

Figure 4: Spectrum after three modules of the radiator.

SIMULATIONS

For the simulation of HGHG seeding at the 14th harmonic of the 267-nm seed (FEL wavelength 19.0 nm), an electron distribution with an energy of 1.0 GeV is generated in a start-to-end simulation, which tracks the electron bunch from the photoinjector to the start of the FLASH2 undulator beamline using the simulation codes ASTRA [12] and CSRTRACK [13]. The selected machine parameters optimize the emittance and the slice energy spread below 2 mm mrad and 150 keV, respectively, at a peak current of 1.0 kA. For a more detailed description of the start-to-end simulations, the reader is referred to Ref. [11].

The simulation of the actual HGHG-seeded FEL at the 14th harmonic requires two runs of the code GENESIS 1.3 [14]. In the first simulation run, the energy-modulated phase-space distribution (at the end of the modulator) is generated. The second simulation run uses the modulated phase-space distribution to simulate the bunching chicane and the seeded FEL process in the radiator undulator. Figures 3 and 4 show the temporal power profile and the spectrum of the seeded FEL pulse close to saturation after three modules of the radiator. Different options to operate the radiator are currently under study.

SUMMARY

We presented a proposal for an upgrade of DESY's FEL beamline FLASH2 to seeded FEL user operation. The initial implementation phase will provide HGHG-seeded operation down to wavelengths of 19 nm at 10 Hz repetition rate. After upgrading the seed laser system, 100-kHz burst-mode HGHG-seeded FEL operation would become available. In combination with the superconducting linear accelerator, this laser enables to generate up to 800 seeded FEL pulses per second.

ACKNOWLEDGEMENTS

We acknowledge discussions with colleagues from DESY accelerator division, DESY photon science, and University of Hamburg.

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