CONCEPTUAL IDEAS FOR THE TEMPORAL OVERLAP OF THE ELECTRON BEAM AND THE SEED LASER FOR SFLASH*

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Abstract
sFLASH is a seeding FEL experiment at FLASH/DESY, to introduce a 30nm high harmonic gain (HHG)-based XUV-beam laser to the electron bunches of FLASH at the entrance of a 10m variable-gap undulator. The temporal overlap between the electron beam and HHG is important for the seeding process. The installation of a 3rd harmonic cavity at FLASH will provide a long high current electron beam (at kA level) over ~ 600 fs Full-Width at Half-Maximum (FWHM) bunch duration. The duration of the HHG laser pulse will be about 30fs (FWHM). The desired overlap can be achieved in steps. One approach will be to synchronize the drive laser (Ti: Sapphire, 800nm) of HHG and the incoherent spontaneous synchrotron radiation of the undulator at a sub-picosecond precision. In a following step the overlap can be improved by scanning within the sub-picosecond uncertainty. The possibility of using a streak camera to detect both the 800nm laser and the spontaneous undulator radiation pulses without perturbing FLASH user operation is investigated. To match the power levels, the laser beam has to be attenuated by several orders in magnitude. The layout of the experiment and preliminary simulation results of generation and transport of both light pulses are presented.

INTRODUCTION

Seeding a FEL with High Order Harmonics generated in Ar gas would be a good means for generation of more intense and fully coherent short wavelength radiation. The seeding will be carrying out on the Free electron LASer in Hamburg (FLASH) [1].

For the HHG part, the laser system which would be used for the generation of HHG light is based on the Chirped Pulse Amplification (CPA) Ti:Sapphire technology, which delivers high energy IR laser beam (10Hz, 30 fs (FWHM), 50 mJ). Some parameters of the HHG radiation are indicated in Table 1.

To present, FLASH is operating with a non-linear chirp on the electron beam, which results in an effective bunch length of less than 10 fs after compression. The rms bunch arrival-time jitter is about 200 fs [2], which would make seeding with a short pulse difficult. In order to decrease the magnitude of these fluctuations and to lengthen the electron pulse, a 3.9GHz RF cavity [3] will be installed, resulting in 600 fs FWHM electron pulses.

In sFLASH project the HHG would spectrally selected and spatially and temporally will be overlapped with the synchrotron radiation due to the electron beam (600 fs FWHM).

The final layout of the sFLASH project consists of 4 undulators of 10 m total length with variable gap, which is suitable to achieve the desired wavelength.

Table 1: Seed Parameters

Seed Parameters	
Wavelength (nm)	30
Pulse duration (fs)	30
Energy in Harmonic (nJ)	1

TIMING REQUIREMENT

One of the main tasks in achieving seeding is to find transverse, longitudinal and spectral overlap between electrons bunches and HHG pulses with high accuracy: The spatial overlap of about 20 micrometer and temporal overlap of several 100fs is required. The transverse overlap between two pulses will be achieved by measuring their respective position on a YAG crystal at either end of the first sFLASH undulator.

EXPERIMENTAL REALIZATION

For the temporal overlap between HHG pulses and electron bunches, the relative jitter should not exceed 40 fs rms, so the electron bunch arrival time has to be actively stabilized using an intra-pulse train feedback [2] regulating the gradient of the accelerating modules prior to the first bunch compressor stage. For the feedback, the electron bunch arrival time is detected by sampling a fast transient signal from a broadband pickup using laser pulses from a femto second stable optical synchronization system [4]. The seed laser system is locked with femtosecond precision to the optical synchronization system using a two-colour balanced optical cross-correlator currently under development [5].

To do the initial temporal alignment of the seed pulse with the electrons, we plan to guide radiation from the infrared pulse driving the HHG and synchrotron light generated from the electron beam onto a single detector.

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A part of the infrared pulse is transmitted through the argon cell and co-propagates with the HHG radiation along the beam line.

We plan to couple this radiation out of the vacuum and detect it together with spontaneous synchrotron radiation from an undulator which has been installed for the Optical Replica Synthesizer (ORS) experiment [6].

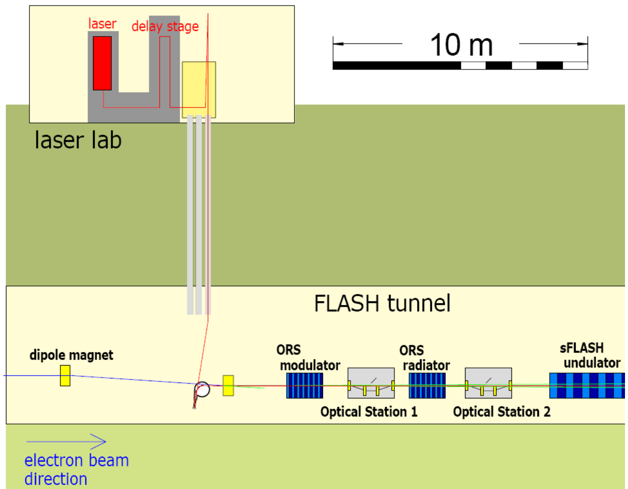

Figure 1: ORS and sFLASH section of FLASH

A general layout of the experimental setup for the synchronisation is shown in Figure 1. The drive laser for the HHG (indicated in red) will propagate approximately coaxial with the higher harmonics through the laser transfer line and into the electron beam pipe. Due to the larger divergence of the driving laser with respect to the higher harmonics one could use an off axis mirror to reflect part of the beam out of the electron beam pipe.

The different signals from the electron beam discussed above are also indicated. The electromagnetic modulator from the ORS experiment installed in FLASH [6] has a maximum K parameter of 8.4. With an electron energy of e.g. 1 GeV the fundamental harmonic can be tuned up to 950 nm wavelength.

The following types of detectors are intended to measure the arrival time difference of the laser and the signals from the electron beam respectively: A fast Photodiode (PD) based on GaAs detectors with a cut-off frequency of 10GHz and a Multi-Pixel Photon Counter (MPPC). The advantages of the photo diodes and the MPPC are that they are relatively cheap and easy to align in the tunnel. However, they only provide a temporal resolution in the order of 100 ps. Fine scanning of the timing differences of laser and electron beam using a mechanically or electronically delay stage has to be done afterwards. A more precise way to achieve the temporal overlap is using a streak camera with a temporal resolution of down to 200 fs. However this device has to be aligned carefully to reach the high resolution and it has to be secured against radiation when installed in the accelerator environment.

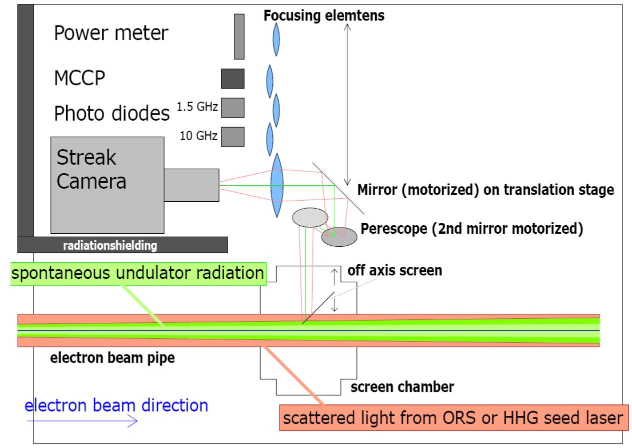

Figure 2: Planned layout for the diagnostics on one of the optical stations. Undulator radiation and laser light will be reflected by on off axis screen

Figure 2 shows the planned layout of the devices on one of the optical stations within the ORS section in FLASH. An off-axes screen will reflect part of the HHG drive laser and a fraction of the undulator radiation from the first ORS undulator onto the optical station. Here a periscope and a mirror on a translation stage can be used to switch between the different detectors. Motorisation of the last periscope mirror and the switching mirror will guarantee the alignment possibility for position and angle of the different beams.

The usability of this system together with the remote operation and alignment of the streak camera (Hamamatsu FESCA-200 C6138) [7] will be tested in the Terahertz and Optical SYnchrotron radiation LABoratory (TOSYLAB) at FLASH in the upcoming months.

So in this regard some measurements will be done to see the effect of the synchrotron light intensity in the final output to have a rough estimate about the required minimum photons for the operation of streak camera.

The other goal is to see the possibility of reaching to saturation, since we are interested to the time differences between two signals due to laser and synchrotron radiation.

SIMULATIONS

For measuring the synchrotron light and the HHG drive laser simultaneously one has to attenuate the laser in order to avoid saturation or damage of the detectors described above. Therefore simulations of the laser beam propagation through the transfer line as well as simulations of the synchrotron radiation from the undulator were done using the optical design software ZEMAX [8] and SRW [9].

Figure 3 shows a part of the laser transfer line modelled in ZEMAX were a focusing mirror at normal incidence as well as three mirrors to bend the HHG into the electron beam pipe can be seen. A detector is placed at the same position where the reflecting off-axis screen on the optical stations will be situated. It is used to determine the radiation power of the propagated laser beam. For the simulation a 800 nm laser pulse energy of 10 mJ and a pulse duration of 30 fs (FWHM) is assumed.

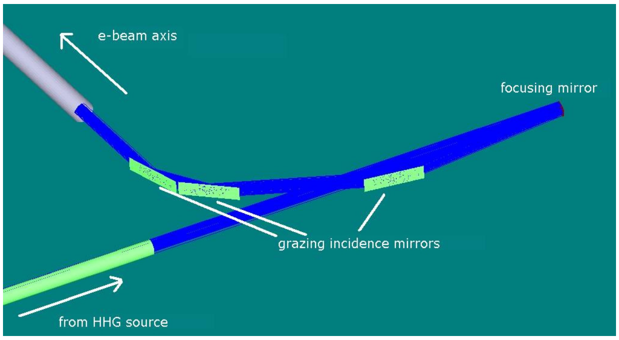

Figure 3: Part of the ZEMAX model of the HHG laser transfer line

For the same screen the photon flux on it will be simulated with SRW using the electron optics designed for the sFLASH project [10]. The wavelength range for the simulation is determined by the spectral response of the different detectors (300 – 800 nm). The screens for the simulation has a dimension of 20x20 mm² with the centre placed 15 mm above the electron beam axis. Thus, the edge of the screen has a distance of 5mm to the electron beam One screen is situated on Optical Station 1, 2.4m downstream the undulator and one on Optical Station 2 with a distance of 7.3m to the undulator. The latter is tuned to 800 nm at electron energy of 1 GeV. Detailed information about the ORS undulator parameters can be found in [11].

RESULTS

The results of the ZEMAX simulation are shown in Table 2. The source is a pulse with 10 mJ pulse energy and 30 fs (FWHM) pulse duration. The Transmission is shown for a position after all bending mirrors at the entrance of the electron beam pipe and for the position of the optical stations 1 and 2 for an on-axis and a 5mm off-axis screen.

Table2: Result of the ZEMAX simulation for the Transmission of the HHG drive laser

Source	100,0%
Entrance of electron beam pipe	32,0%
on-axis screen on OS1	30,7%
5 mm off-axis screen on OS1	2,0%
on-axis screen on OS2	28,9%
5 mm off-axis screen on OS2	0,6%

Figure 4 shows the simulated spontaneous emission on the two off axis screen after the undulator. Expressed in the emitted energy of radiation per electron bunch one gets the values shown in Table 3.

Table 3: Simulated pulse energies

	Pulse Energies in pJ	
	on-axis	off-axis
OS1	2,6	0,5
OS2	0,82	0,57

The undulator radiation is more than eight orders of magnitude less intense on OS1 and six orders on OS2. One could use a wavelength filter or a polarizer to attenuate the laser light.

Another possibility to increase the estimated power of synchrotron radiation the electron beam could be entering to the undulator by an angle (~1mrad) respect to the axis of the undulator. This could be done using steerer magnets in the entrance of undulator to bend the electron beam.

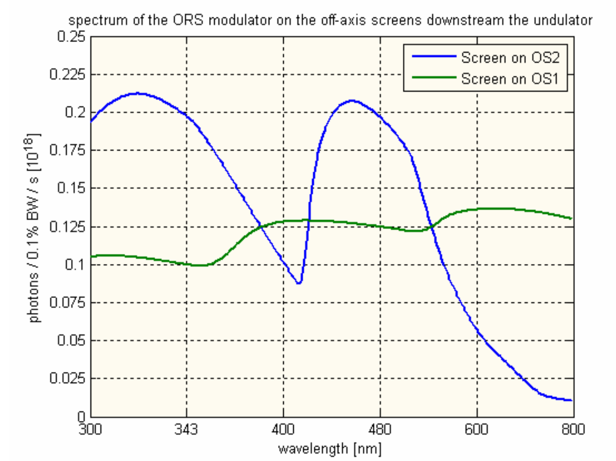

Figure 4: Photon flux on the two screen 2.4 m and 7.3 m after the ORS modulator.

CONCLUSION

To achieve temporal overlap between the seed pulse and the electron beam, we plan to use radiation from the drive laser and synchrotron radiation from the electron beam. The energies of these radiation pulses have been simulated using the code ZEMAX and SRW.

According to the results of this simulation the energy of the driven laser beam on the screen in optical station one and two is expected to be 200 uJ and 60 uJ respectively, which still has to be attenuated to be within dynamic range of the photo detectors and comparable to the synchrotron radiation light.

This has to be compared to synchrotron radiation pulse energies of ~ 0,5 pJ. Various possibilities will be explored to measure these two pulses on the same detector.

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