FEMTOSECOND TEMPORAL OVERLAP OF INJECTED ELECTRON BEAM AND EUV PULSE AT sFLASH *

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Abstract

sFLASH is a seeded experiment in Free Electron Laser in Hamburg (FLASH) [1], which uses a 38 nm high harmonic gain (HHG) based EUV-beam laser in tandem with FLASH electron bunches at the entrance of a 10 m variable-gap undulator. The temporal overlap between the electron and HHG beams is critical to the seeding process. Use of a 3rd harmonic accelerating module [2] provides a high current electron beam (at the kA level) with ∼600 fs FWHM bunch duration. The length of the HHG laser pulse will be ∼30 fs FWHM. The desired overlap is achieved in steps. First is the synchronization of the HHG drive laser (Ti: Sapphire, 800 nm) and the incoherent spontaneous radiation from an upstream undulator. Next, the IFEL [1]-modulated electron bunch will pass through a dispersive section, producing a density modulation in the beam. This in turn yields emission of coherent radiation from a downstream undulator or transition radiation screen when the longitudinal overlap of the two beams is achieved. The coherently enhanced emitted light will be then spectrally analyzed. The experimental layout, simulation results of generation and transport of both light pulses, and preliminary measurements are presented.

INTRODUCTION

Seeding an FEL with high order harmonics generated in Argon gas (HHG) is a good means for generation of short wavelength radiation having full coherence at high intensity.For the HHG part, the laser system which would be used for the generation of HHG light is based on chirped pulse amplification (CPA) Ti:Sapphire technology, which delivers a high power, short pulse 800 nm wavelength laser beam (30 fs FWHM, 40 mJ) at 10 Hz.

So far FLASH was operating with a compression scheme producing electron bunches with an effective length in order of 10 fs [3] after compression. The rms bunch arrival-time jitter is about 200 fs [3], which makes seeding with a short pulse difficult. In order to decrease the magnitude of these fluctuations and to lengthen the useful duration of the electron pulse in preparation for sFLASH, a 3.9 GHz RF cavity [2] has been installed, resulting in 600 fs FWHM electron pulses. In the sFLASH project the desired HHG harmonic is spectrally selected and spatially and temporally overlapped with the electron beam. The final layout of sFLASH consists of 4 undulators with variable gap that allows wavelength selection, having 10 m total length. To achieve the seeding, accuracy of spatial overlap about 20 μm and temporal overlap of several 10 of fs is required [4]. The transverse overlap between two pulses will be achieved by measuring their respective position on a YAG crystal between sFLASH undulators [5]. The temporal overlap of two pulses will be found with using two methods. First, as streak-camera based approach will be employed that simultaneously measures the remanent 800 nm laser and undulator radiation from the electron beam. Later, a finer resolution ORS-based [6] system will be used in which the 800 nm laser imprints a energy modulation onto the electron beam via the IFEL process, which will be used to produce a coherent radiation signal.

EXPERIMENTAL SETUP

For the temporal overlap between HHG pulses and electron bunches, the The following steps are planned to find the temporal offset between the HHG drive laser and the prompt signals from the electron beam:

- A part of the IR pulse is transmitted through the Argon cell and co-propagates with the HHG radiation along the beam line. To perform the initial temporal alignment of the seed pulse with the electrons, the IR driving the HHG and the radiation generated from the electron beam inside the ORS undulator will be guided onto a fast photodiode (PD) based on GaAs detectors with a cut-off frequency of 10 GHz and a photomultiplier (PMT). They provide a maximum temporal resolution of 100 ps. Fine scanning of the time difference between laser and electron beam will be done by using a mechanically or electronically delay stage.
- After initial temporal alignment with the PD or PMT, the more precise overlap can be done with using the streak camera (SC), FESCA 200 fs, [7] with a temporal resolution $\geq$ 200 fs. This is a higher challenge, as the SC has to be aligned carefully to reach the high

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[1] Inverse FEL

resolution and it has to be protected against radiation when installed in the accelerator environment.

- The ORS [2] setup will be employed to scan the temporal and spatial overlap of two pulses better than 200 fs, using IFEL modulation to produce 800 nm coherent signals using transition or undulator radiation. An spectrometer has been installed after the second undulator in the ORS setup to observe the enhancement of the coherent light.

Transport of optical and HHG pulses

The experimental setup for finding the longitudinal overlap is installed after first ORS undulator, as illustrated in Fig. 1. An silver coated OTR screen will reflect the IR laser and the undulator radiation to the station where the PD and SC are installed. After the screen reflection, the light pulses traverse a joint beam line to reach the detectors. Two motorized translation stages, and two motorized micrometers allow remote position adjustment. For coarse initial timing, the above mentioned PD-PMT system is placed on a motorized translation stage with a CCD camera, which allows the alignment of the two beams. A convex lens with focal length of 500 mm will focus the light to the entrance slit of the streak camera and PD.

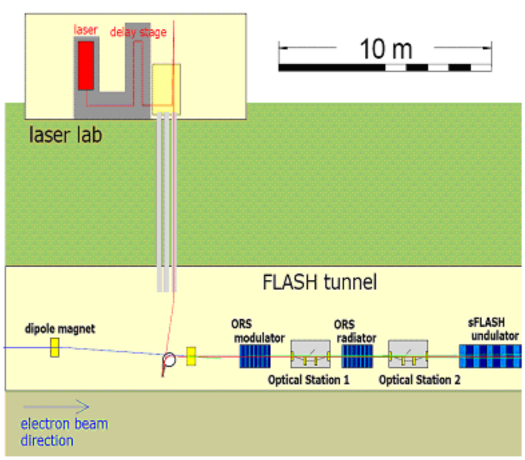

Figure 1: The sFLASH layout

Radiation Shielding

We have installed our electronic equipment and PCs in a radiation shielded container made of composite materials consisting of lead (20 mm) and borated polyethylene (16 mm) plates. Our primary aim is to reduce the γ dose to a prescribed level to extend the life of the electronic components, and to cut off the thermal neutrons triggering soft errors, or Single Event Upsets (SEU) in the delicate microelectronics. [8]

[2]Optical Replica synthesizer

ORS undulator spectrum

As a reference for the timing of the electron bunch, the synchrotron light of the 1st ORS undulator (5 period, 200 cm periodic length), is coupled out of the beam line with an OTR screen, and will be guided to the streak camera. The simulation result for this undulator spectrum is indicated in Fig. 2. In this simulation the undulator is tuned to 800 nm. The magnetic field B=0.33 T, and the K=6.2. Due to the large K value enhancement of the number of photons in harmonics can be shown. According to the simulation the total power over the spectrum, for the 10 Hz machine operation, is 450 KW.

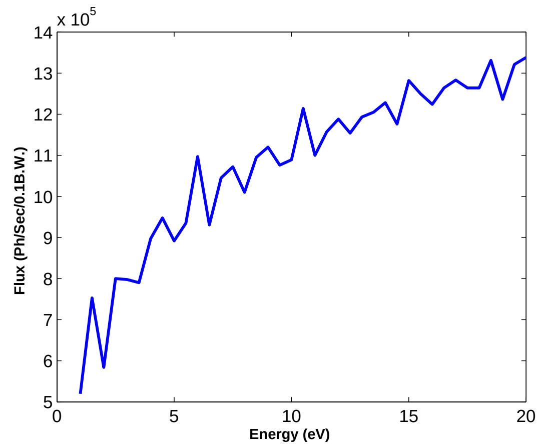

Figure 2: ORS undulator spectrum

SIGNAL FILTERING AND ATTENUATION

The energy of the incoming light to the SC should be kept below the damage threshold. Based on the measurements done with 800 nm laser, the Photocathod saturation threshold can be reached with energies more than a few nJ.

Reflectivity of grazing incidence(GI) mirror

The beam line that transports the IR laser from the HHG source to the undulator consists of four grazing incidence and one focusing mirror (1") with a different coating. The grazing incidence mirrors are made of B4C or a combination of B4C and Mo cap layer, which are custom-made to reflect the 30 nm beam. Focusing will accomplish with a Mo-Si multilayer mirror having good reflectivity at 800 nm. In the experiment the reflectivity of the grazing incidence mirror for differing angle and polarization has been measured and is demonstrated in Fig. 3.

This measurement indicates attenuation of the IR laser between 3 to 5 order of magnitude.

Attenuation by using spectral filter

The large spectral range of the undulator radiation can cause an elongation of the pulse due to dispersion in air, the

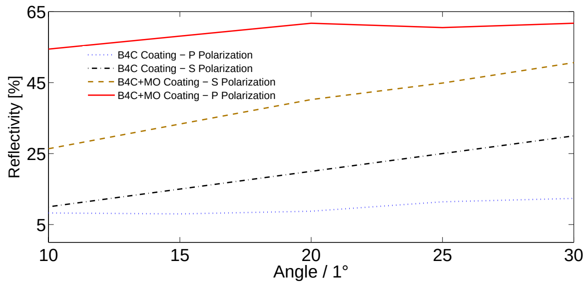

Figure 3: Reflection of GI mirrors for IR laser

window, the internal SC optics and the lens used to focus on the SC slit. To avoid the temporal dispersion, equalize the number of photons of the two different pulses and reduce the energy to a safe level for the SC, the spectral filters are used. The setup contains two filter wheels, so that a proper filter combination can be choosen. Measurements and calculations have shown that e.g. a bandpass filter with 700 / 750 / 800 nm central wavelength and 80nm band width would reduce the laser energy by a factor of about 70 / 5 / 2 and the undulator radiation in the order of about 10. Also different short and long pass filter will be combined for reach an appropriate energy level.

FINE RESOLUTION OVERLAP MEASUREMENTS WITH ORS SYSTEM

The SC resolution is limited to hundreds of fs, due to slit size, spatial photon profile, space-charge effects and sweep rate.For the more accurate overlap of the seed pulse with electron bunch, which has profile notable features, the 100's of μJ IR laser energy will be focused with a different focusing mirror at the beginning of ORS undulator and will interact with electron bunches. In this IFEL process the electrons are energy modulated. This effect will induce a density modulation after the beam passes through the chicane with an R_{56} that can be varied up to 250 μm, with the effect illustrated in Fig. 4.

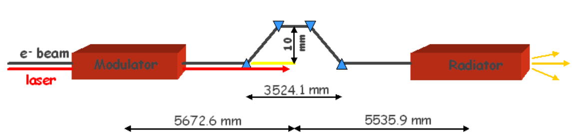

Figure 4: Schematic diagram of ORS setup

The density-modulated beam can then be passed through the second (horizontally polarized) ORS undulator and emit coherent spontaneous radiation, which is reflected to a spectrometer by an OTR screen. The enhancement of the coherent over incoherent light will be around 6 orders of magnitude, which can be observed in case of perfect overlap of IR laser and electron bunch. The fundamental bunching (B_n) and enhancement of the coherent radiation (E_n) are given by Eq. 1 and Eq. 2 [9]:

$$FB = 2J_1\left(IE\frac{2\pi}{\lambda_L}\frac{R_{56}}{E_e}\right)\cdot\exp\left[\frac{-1}{2}\Delta E^2\left(\frac{2\pi}{\lambda_L}\frac{R_{56}}{E_e}\right)^2\right] \quad (1)$$

$$E_n = B_n^2 \cdot N_b \quad (2)$$

Which the induced energy modulation IE=140 keV, $R56$=200 μm, the electron beam energy E_e=820 MeV, the laser wavelength λ_L=800 nm, and the uncorrelated energy spread ΔE=500 keV.

The enhancement of coherent light as a function of chicane R_{56} is plotted in Fig. 5

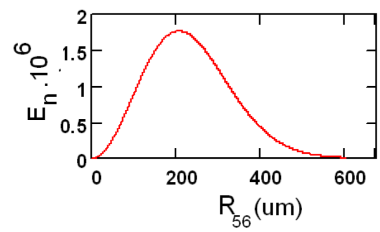

Figure 5: Coherent Enhancement in ORS undulator

CONCLUSION

The coarse temporal overlap between HHG laser and electron bunch will be achieved by using PMT and fast FD. The picosecond to femto second temporal overlap in sFLASH project will be achieved by using streak camera installed in the tunnel. By using ORS setup in FLASH tunnel further scan to find the more accurate overlap of two beams will be done. The setup is installed and aglined to the IR laser and will be commissioned next month.

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