NEW USES FOR THE ORS SECTION AT FLASH

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Abstract

The Optical Replica Synthesizer (ORS) section at the Free-electron LASer in Hamburg (FLASH) was constructed to make longitudinal electron bunch profile measurements and to diagnose the stability of the synchronization of the electron beam and the sFLASH High Harmonic Generation (HHG) laser system. The section enables the co-propagation of an electron bunch and a laser pulse through a sequence of magnetic components: undulator, chicane, undulator, chicane. There are several ways that this section could be used that have not yet been attempted. These include: Echo Enabled Harmonic Generation (EEHG), beam slicing with a few-cycle laser pulse, a new type of Electro Optical Sampling (EOS) with Frequency Resolved Optical Gating (FROG), and a new form of optical replica experiment which measures the changes in the spectrum and profile of the laser beam directly after the first ORS undulator. This paper aims to introduce the design and limitations of these experiments and to specify the items that can be installed in order to make them happen.

INTRODUCTION

Based on the theoretical work of Saldin, Schneidmiller and Yurkov [1], the Optical Replica Synthesizer (ORS) section at FLASH was designed to measure the longitudinal profile of the electron beam. It was first constructed in 2007 through a collaboration between DESY and the Universities of Uppsala and Stockholm [2-5]. It was then commissioned in 2008 [6-10]. Today, following a complete rebuild of the section, the ORS setup is only used to diagnose the stability of the synchronization between the electron beam and the sFLASH High Harmonic Gain (HHG) laser system [11]. It was envisioned that the 800 nm laser beam used to generate the high-harmonics for HHG could also be used to do ORS experiments. The mirrors used to transport the XUV HHG beam are, however, entirely inappropriate for transporting the 800 nm beam and the power levels of 800 nm which they could supply for ORS experiments are insufficient. During the last three months of 2011, a new, 12 meter laser transport line will be constructed, connecting the laser lab to the electron beam transport pipe in the FLASH tunnel, enabling new ORS experiments in 2012 (Fig. 1).

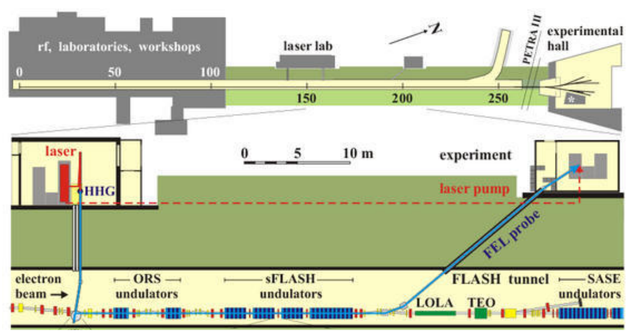

Figure 1: Cross-sections of the laser lab in building 28g and the FLASH tunnel. An additional laser transport line running parallel to the XUV laser transport line (vertical blue line on left) is needed for the ORS section. The figure has been taken from sFLASH documentation.

Besides the original ORS measurement, several other types of experiments will be made possible through the installation of this new laser transport line. These experiments include: Echo Enabled Harmonic Generation (EEHG), beam slicing with a few-cycle laser pulse, Electro Optical Sampling (EOS) with Frequency Resolved Optical Gating (FROG), and a new form of optical replica experiment which measures the changes in the spectrum and profile of the laser beam directly after the first undulator.

These new experiments can make use of the infrastructure and diagnostics built for sFLASH without requiring major hardware investments. In addition, they address key areas of research for FEL seeding and diagnostics decisions. In this paper, the scientific cases for these experiments are described, along with their requirements and limitations. The feasibility and anticipated costs of these experiments are also presented.

ORIGINAL METHOD: ORS

The ORS method originally proposed in [1] requires that the electron beam co-propagates with a laser beam through a sequence of magnetic components: undulator, chicane, undulator, chicane (Fig. 2). The energy of the electron beam is modulated by the laser pulse in the first undulator, the energy modulation is converted into a density modulation in the first chicane and the electron bunch radiates an optical replica in the second undulator. The optical replica should have a longitudinal profile which is identical to that of the electron beam and because

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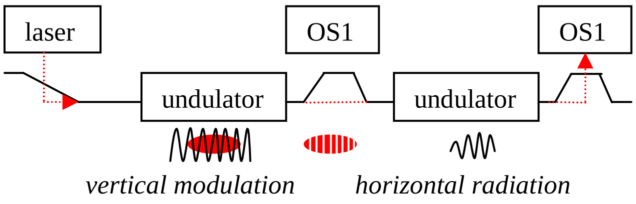

Figure 2: Layout of ORS section and modulator-radiator concept. The laser diagnostics are installed on the optical tables labeled OS1 and OS2. Screens and cameras are distributed throughout the section to enable transverse overlap of the laser and electron bunch. A FROG device is installed on the optical table labeled OS2.

the second undulator causes the beam to oscillate in a plane which is perpendicular to that of the first undulator, the optical replica pulse radiated in the second undulator can be separated from the seed laser pulse with a polarizer and then measured with a FROG device. FROGs measure the longitudinal profiles of laser pulses. The longitudinal profile of the electron bunch measured with the ORS experiment can then be directly compared to the longitudinal profiles measured with the LOLA transverse deflecting cavity setup. The advantage of the ORS method over the LOLA method is that ORS does not destroy the electron bunch which it is measuring. The resolutions of the two methods are comparable but they have different sensitivities to beam diameter and energy spread.

The ORS setup can also provide valuable diagnostic for any experiments that require a high level of laser pulse - electron beam synchronization. When the microbunched electron beam is incident upon an OTR screen in OS1, the coherent radiation which is emitted is several orders of magnitude stronger than when a non-microbunched electron beam is incident upon the screen. Thus, when the OTR signal is maximized, one is assured that the longitudinal overlap between the electron beam and the laser pulse has been optimized. This has been used to optimize the synchronization for the sFLASH HHG experiment and can serve as a diagnostic for optical synchronization systems which attempt to generate femtosecond synchronization between the electron beam and an external laser [12].

During the commissioning of the ORS experiment in 2008, about a milli-Joule of 800 nm laser power was available with a pulse length of a few hundred femtoseconds and it was determined that it was insufficient for optimal operation [6-10]. It was decided that in future experiments, 10 mJ pulse energy over a picosecond pulse length should be used. The 800 nm beam which is used to produce the harmonics for the sFLASH HHG experiment typically has 30 mJ of pulse energy with a pulse length which can be easily adjusted between 300 fs and a picosecond [11]. This would be an ideal laser pulse for 800 nm ORS experiments if an adequate laser transport line were in existence.

The present laser transport line was built for the XUV beams of the HHG experiment and each of the 4 XUV mirrors in the transport line cause a ~50% loss for non-XUV beams. This would leave less than a milli-Joule of pulse energy for the ORS experiment, a value which was determined to be insufficient during the 2008 commissioning phase.

Measurements of the reflectivity of the Molybdenum coated and uncoated XUV mirrors for different incident angles and polarizations are plotted in Fig. 3. While the XUV carbide mirrors which are uncoated with Molybdenum only reflect 10% of p polarized 800 nm light and 35% of s polarized light, the coated mirrors reflect 40% of p polarized light and 60% of s polarized light. The dependence of the reflectivity on the angle of incidence is weak.

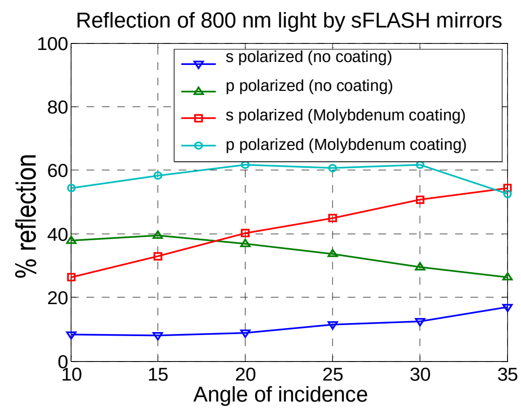

Figure 3: Reflectivity of 800 nm light on XUV mirrors as a function of incident angle (degrees) for different polarizations and mirror coatings. Measurement from R. Tarkeshian (DESY).

In the chamber used to couple the XUV beam into the e-beam pipe, both coated and uncoated XUV mirrors can be moved in and out of the path of the laser. When the XUV mirrors are moved out of the laser path, a non-XUV beam could be passed through an alternate laser port which was originally used for an alignment laser (Fig. 4), but this would require the construction of a new, non-XUV laser transport line running across the tunnel.

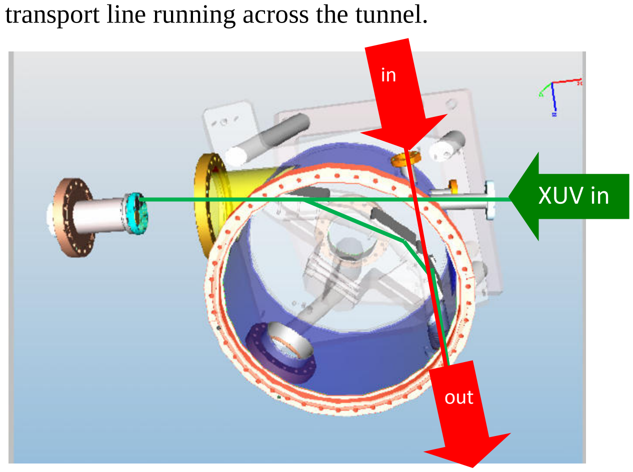

Figure 4: Top-view of mirror chamber. XUV mirrors can be moved down, out of the path of the alternate laser port.

Due to the laser safety requirements attendant to using 800 nm light and concerns about LSCA microbunching gain at 800 nm, parasitic operation of the experiment with this wavelength is not easy to achieve [13]. For this reason, it is more practical to conduct the experiment parasitically with 270 nm and a single-shot TG-FROG to measure the pulse duration. Since an EEHG experiment will operate with 270 nm, this provides an ideal opportunity to test this method. The resolution of the method will also benefit from 270 nm operation, due to the fact that the phase slippage in the undulators will be 3 times smaller, compared to the original 800 nm experiment.

NEW METHOD: rORS

An alternative to the original ORS method has been pursued by Florian Gruener. Where the original ORS method uses a FROG installed after the second undulator section (radiator), the new method would involve a FROG installed after the first undulator section (modulator) (Fig. 5). The new, reduced ORS (rORS) experiment intends to measure the change in a laser pulse's spectrum and spectral phase as caused by the interaction with the electron bunch in the first undulator. It is similar to a scheme used at LBL to quantify the laser-electron beam interaction in a beam slicing experiment [12], but where the BNL experiment only measured the spectrum, the rORS method would also use a FROG to measure the longitudinal profile of the pulse. It is anticipated that this new method would be suitable for the measurement of ultra-short electron beams and a background-free measurement is possible when making use of polarization effects.

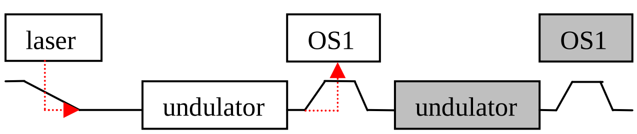

Figure 5: The rORS method requires laser/electron beam interaction in the first undulator. A spectrometer, FROG, and streak camera are/can be installed on an optical table labeled OS1. The last undulator is not required for this scheme.

NEW METHOD: EOS WITH FROG

With an electro-optical crystal installed in the laser beam path, one could also use a FROG together with the high power of the laser beam to do single-shot Electro-Optical (EO) measurements of the longitudinal profile of the electron beam (Fig. 6).

An ideal location to insert a crystal presently exists in the form of an unused vacuum flange between the 2nd and 3rd dipoles of the first ORS chicane. At that location, the electron beam can be positioned off-axis, so that a laser pulse with a large, 10 mm (FWHM) beam diameter could be used. An untried EO experiment using a percolation film instead of a crystal could also be attempted with this setup.

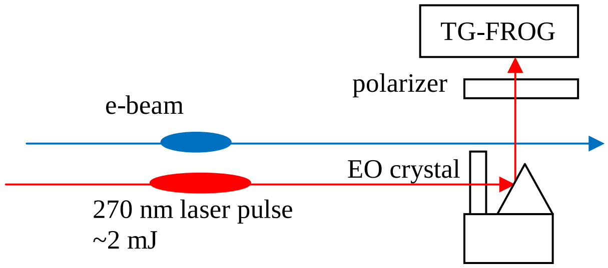

Figure 6: EOS using a FROG could be added to OS1 with minimal effort.

Typical EOS methods require much less (nJ, μJ) laser power than an EOS method using a FROG (mJ) [13] and that is why it has not ever been attempted. Since the laser, optics and diagnostics for this experiment would be already in-place in the ORS section, a good opportunity to test this method is afforded. The unusual option of conducting the experiment with up to 2 mJ of 270 nm light would also be afforded due to the new echo-seeding infrastructure. This experiment will, however, not be prepared for 2012.

ECHO-SEEDING

Typical EEHG or echo-seeding schemes call for a large (1-10 mm) R_{56} in the first chicane [14-17] and when one sees that the ORS section chicanes can only achieve a maximum R_{56} of 130 μm, one is initially inclined to reject the possibility of doing EEHG experiments with this section, even though the – undulator, chicane, undulator, chicane – layout looks appropriate. However, one only needs a several millimeter R_{56} in the first chicane if one is trying to generate large harmonics (>60th) with a conservative amount (<GW) of laser power. When the FLASH correctors installed in the first ORS chicane are replaced with larger HERA correctors, a 700 μm R_{56} can be achieved in the chicane and an EEHG program can be pursued in 2012 with wavelengths in in the same range as those pursued by the sFLASH HHG experiments. The tolerances of these experiments and experimental hardware required to generate and transport the 270 nm seed are described in accompanying TESLA-FEL-NOTEs [22, 23].

An attractive option in the ORS section at FLASH is to generate the 19th harmonic of 270 nm so that the beam could lase with 14 nm in the sFLASH undulators. If the beam energy is set to 1.15 GeV, there is then the possibility to use the 14 nm sFLASH radiation in an HGHG scheme to seed 4.7 nm in the SASE undulators. Given the flexibility of choosing EEHG harmonics, it should be possible to commission EEHG parasitically.

EEHG is a new technique that not many facilities will be equipped to attempt in the near future. It can be partially attributed to luck that the ORS section is so ideally suited to do EEHG experiments in 2012. Even an echo-seeding harmonic number greater than 5 would be an achievement that no other lab has attained [24].

BEAM SLICING WITH A FEW-CYCLE LASER PULSE

With an Optical Parametric Amplifier (OPA) it is possible to use the existing 800 nm light to generate a few-cycle pulse with a wavelength of 4 μm. These pulses would need to be generated in and transported in vacuum and the evacuated transport line which is being built for ORS and EEHG provides a good starting point for developing this infrastructure.

A 4 μm wavelength has the potential to modulate the energy of a slice of the electron beam so that it can be bunched in the ORS chicanes. The slice of the bunch with the highest charge density could then lase before the rest of the bunch, creating a few-fs pulse of light. Improved contrast with the SASE background could be achieved with a pinhole spatial filter. This will not be prepared for 2012.

REQUIREMENTS OF NEW LASER TRANSPORT LINE

A new laser transport line for this section should be able to accommodate all of these different experiments and laser beams. Construction of this vacuum transport line will be completed by December 2011.

Mirrors and optics that accommodate all wavelengths do not exist, so any mirrors installed in the beam line should be easy to replace as needed for individual experiments. For this reason, it was decided to build a pair of vacuum tight boxes with optical breadboards. A side view of these vacuum tight boxes is shown in Fig. 7, together with the incoming vacuum pipe on the left, the flange mounted steering mirrors on the right and the sFLASH incoupling mirror chamber in the upper right corner. The electon beam direction is into the page.

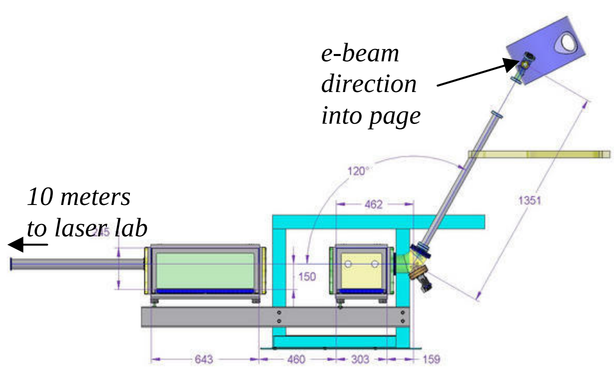

Figure 7: Side view of evacuated laser transport line in the accelerator tunnel. The electron beam direction is into the page in the upper-right corner of the drawing. The laser enters from 10 meters away, on the left-side of the drawing. The boxes contain telescoping, steering and frequency tripling optics.

These boxes are designed to be be easy to open and close and pump-down to 10^{-6} mbar (HV). They are followed by two flange mounted, motorized steering mirrors and they are separated from the machine vacuum (UHV) by a thin window. The laser enters the vacuum pipe through a window 12 meters away, in the laser lab of 28g. More details about the hardware for EEHG can be found in an accompanying FEL note [23].

CONCLUSION

The last 3 months of 2011 will provide an opportunity to install a new laser transport line which will enable several experiments that are not yet possible to do at any other facilities. The EEHG and ORS experiments will be designed to operate fully parasitically. These upgrades will provide for new uses of the sFLASH infrastructure and diagnostics as well as significant contributions from non-DESY personnel and funding sources.

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