

## RESULTS FROM THE OPTICAL REPLICA EXPERIMENT IN FLASH

G. Angelova, V. Ziemann\*, Uppsala University, A. Meseck, BESSY  
 P. Salén, P. van der Meulen, M. Hamberg, M. Larsson, Stockholm University  
 J. Bödewadt, S. Khan, A. Winter, Universität Hamburg  
 H. Schlarb, F. Löhler, E. Saldin, E. Scheidmiller, M. Yurkov, DESY

### Abstract

We present experimental results from the optical replica synthesizer, a novel device to diagnose sub-ps electron bunches by creating a coherent optical pulse in the infrared that has the envelope of the electron bunch and analyzing the latter by frequency resolved optical gating methods. Such a device was recently installed in FLASH at DESY. During a first experiment period the spatial and temporal overlap of a several ps long electron bunch and a 200 fs laser pulse were achieved within an undulator. Coherent transition radiation due to the induced micro-bunching was observed on a silver-coated silicon screen and varying the timing between electrons and laser pulse produced two-dimensional images of the slices as a function of the longitudinal position within the electron bunch. During a second experiment period the strongly compressed electron bunch is modulated by the laser pulse and replica pulses that are emitted from a second undulator are observed by frequency resolved optical gating methods.

### INTRODUCTION

The key for successful experiments at FELs is the accurate and reliable operation of the accelerator. The full characterization of the ultra-relativistic, and ultra-short, electron bunches is a challenging task. However, the measurement of such bunch parameters as the bunch profile, the slice energy spread and the slice emittance is of utmost importance of machine operation and optimization of linac-based SASE free-electron lasers such as the FLASH [3], XFEL [4], or LCLS [5]. This need has triggered the development of new diagnostic methods based on a transversely deflecting cavity [6] or electro-optical sampling [7]. A new method [8] for electron bunch characterization labelled optical replica synthesizer (ORS) at FLASH in DESY Hamburg was proposed in 2005.

The technique uses an external laser to produce fs pulses which interact with the electrons in a modulator undulator creating energy modulation which is transformed into density modulation in the following chicane. The radiator undulator located downstream radiates coherently and the emitted light pulse has the same longitudinal profile as the electron beam. Hence the name Optical Replica Synthesizer. The replica pulse is then extracted from the vacuum pipe by an off-axis mirror and directed to an optical table with optical diagnostics where it is analyzed by

FROG (frequency resolved optical gating) device, called GRENOUILLE [9].

### TECHNICAL LAYOUT

The seed laser is located in a newly-constructed laser hutch. The seed laser system is based on a commercial Ti:Sapphire regenerative amplifier (Clark-MXR CPA2001). However, the standard oscillator for this system has been replaced by a home-built Erbium-fiber oscillator [10] that operates at 1550 nm and at a frequency of about 52 MHz. The pulses of this oscillator are compressed and are subsequently frequency doubled in a 1 mm PPLN crystal before being injected into the amplifier cavity. The seed laser system produces pulses of up to 800  $\mu$ J in energy and, depending on the settings of the compressor, a duration between 170 fs and 3 ps. The Erbium-fiber oscillator is phase-locked to the RF system of FLASH with a timing jitter of approximately 50 fs. The arrival time of seed laser pulses with respect to the electron bunch is varied electronically with the help of a vector modulator that controls the phase lock between the oscillator pulse train and the accelerator RF signal.

To reach the tunnel, the laser pulse travels through a 12 m long laser transport system consisting of remotely controlled motorized mirrors and a three-lens telescope. The first lens has a fixed position; the z-position of the second and the third lens is variable in order to control the laser waist position and size in the laser-electron interaction zone inside the modulator. For diagnostic purposes the laser beam can be deflected with a mirror back to the

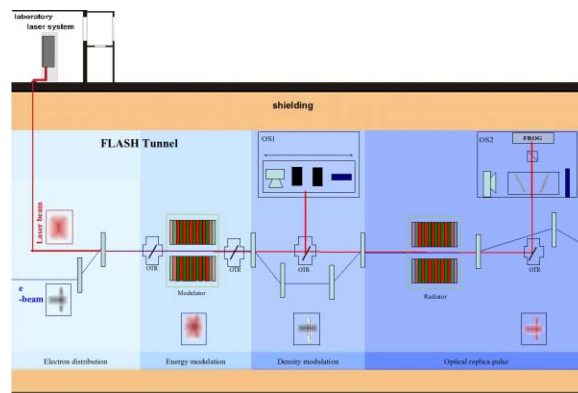


Figure 1: Optical Replica Synthesizer layout in the FLASH Tunnel.

\* Volker.Ziemann@fysast.uu.se

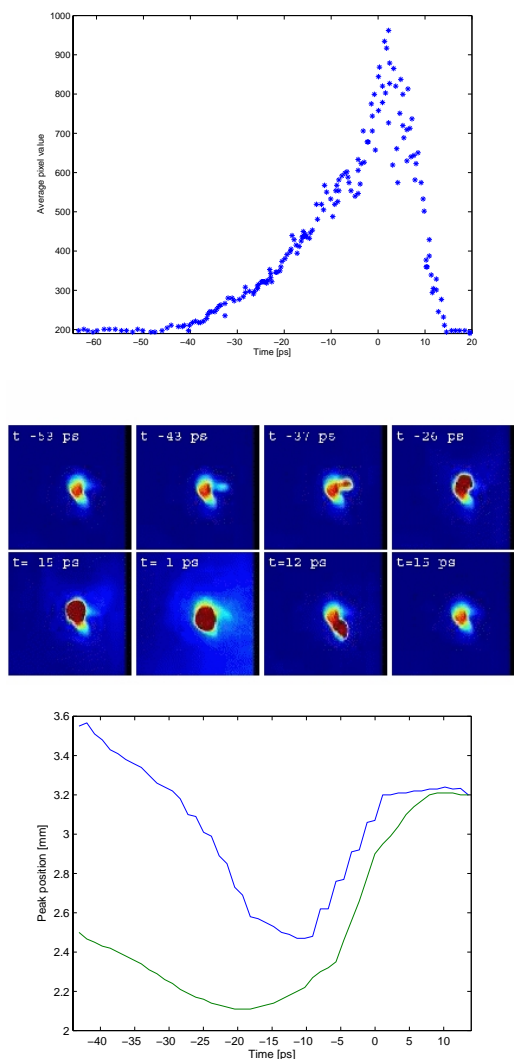


Figure 2: OTR screen on OS2 for different laser arrival times with respect to the electron beam.

laser hut. The laser pulse is extracted from the tunnel into the accelerator beam pipe through a back-tangent window located near the second dipole of a dog-leg chicane.

The laser pulse co-propagates with the electrons, passes the first undulator (the modulator) and is extracted by a silver-coated silicon OTR screen installed in the middle of a four-magnet chicane on the first optical station OS1 which accommodates a camera, photo diodes and a power meter in order to analyze the laser pulse. The electrons continue to propagate through the radiator and pass a second optical station (OS2) where the light created at or reflected from silver-coated silicon OTR screen is guided to an optical table where it is recorded by a Basler A331 camera. The table also houses a power meter and the GRENOUILLE which is used to reconstruct the longitudinal intensity profile and the phase of the replica pulse. For the ORS experiments the electron beam will be directed around the OTR

06 Instrumentation, Controls, Feedback & Operational Aspects

screen on OS2 by three steering magnets, as is shown by the thin line in Fig. 1, but can also be directed onto the OTR screen by switching off the three steering magnets in order to observe the coherent radiation stemming from the micro-bunched beam [11]. Both the modulator and radiator undulator have 5 periods + 2 correction periods, 40 mm gap in order to accommodate 38 mm beam pipe, 0.2 m period length, peak field up to 0.45 T. The modulator is vertically deflecting and the radiator is horizontally deflecting which allows separating the vertically polarized laser pulse from the horizontally polarized replica pulse generated in the radiator.

### EXPERIMENTAL RESULTS

During the first shifts the hardware was commissioned and all subsystems were tested and debugged. The most challenging part was to achieve the laser-electron interaction in the modulator. Here two OTR up and downstream the modulator (see fig.1) are use to accomplish the spatial overlap between laser and electron beam by steering the laser with two upstream mirrors. For the temporal overlap we initially used a longer electron bunch to relax the tolerances. Temporal overlap is achieved by changing the timing of the laser with the vector modulator. In this way a longitudinal slice (of length 200 fs) of the electron bunch is modulated. The minimum step size with this method is around 100 fs. An OTR signal from the electron beam hitting the OTR screen on OS2 was used to find the overlap. The un-modulated electron beam radiates incoherent OTR but once the density modulation is induced, we could see a significantly enhanced coherent OTR signal. We used the average pixel value within a small region of interest on the pictures and plot this as a function of relative timing between laser and electrons. The result is shown on the top of Fig. 2 and a selection of individual pictures are shown below it. Here we see that for large negative times only the incoherent spot from the electrons is visible, but then a small second spot near the top right appears which moves

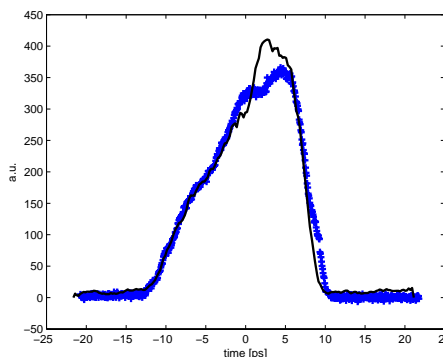


Figure 3: Comparison of ORS measurement (blue) with the transverse deflecting cavity (black).

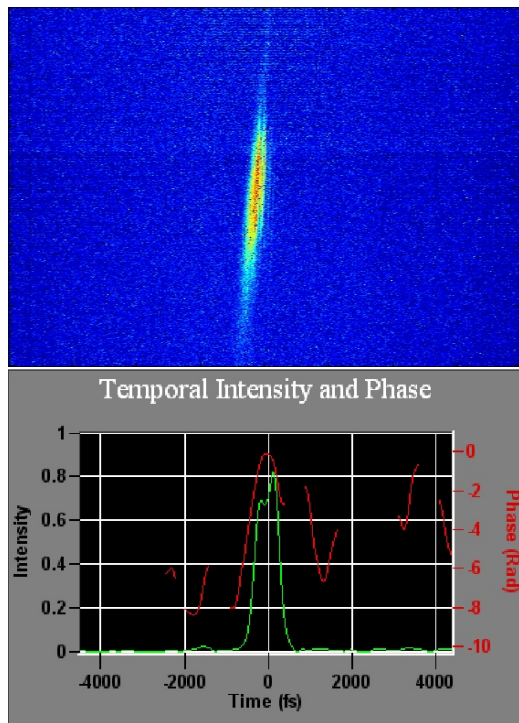


Figure 4: First FROG traces.

through the electron spot in the following and exits near the bottom right. Unfortunately the pictures are badly saturated, a problem that is fixed in later experimental runs by additional neutral density filters in front of the camera. Note that we also can deduce the transverse position of the longitudinal slice that was excited by the laser, as is shown at the bottom of Fig. 2. This feature is discussed in more detail in Ref. [14].

Since scanning the electron bunch with a short laser pulse constitutes a bunch shape measurement we compared the longitudinal bunch profile determined in the ORS overlap scans with that determined by the transversely deflecting cavity LOLA [13] and show the comparison in Fig. 3, which shows very good agreement in the determination of the bunch profile.

During a later block of shifts we carefully aligned the radiation from the radiator undulator and passed it to the power meter on optical station 2. In order to maximize the power we worked with a compressed bunch with a leading spike that has a length on the order of 100 fs and a short laser pulse with a length of 200 fs. After aligning laser and electron beam both spatially and temporally and careful tuning of the accelerator resulted in a measured energy per pulse on the order of  $10 \mu\text{J}$ . This is sufficient to produce FROG traces on the GRENOUILLE which involves second harmonic generation and requires at least this power level. When passing the the pulse from the radiator to the GRENOUILLE we were actually able to observe FROG traces. An example is shown in Fig. 4 which shows the picture from the temporal-spectral GRENOUILLE 8-500-

USB where the horizontal axis is the temporal and the vertical the wavelength axis. In the lower part of Fig. 4 the reconstructed longitudinal intensity profile of the coherent light pulse emitted from the radiator undulator by the modulated electron bunch is shown. We observe that the FROG trace is tilted which suggests that the radiator pulse is spatially chirped and in addition has a tilted wavefront. Note, however, that we have used a short laser pulse to have sufficient intensity available to generate the FROG trace. Ideally we need a somewhat longer laser pulse of about 1 ps and a short pulse GRENOUILLE to make quantitative results about the longitudinal profile of the electron bunch, a task that we will pursue in future runs.

We have benefitted tremendously by the support of the technical crews at DESY. This work is supported by the UU-SU-KTH FEL-center.

## REFERENCES

- [1] S. Khan, et.al., *Status of the Optical Replica Synthesizer at FLASH*, presented at the 22nd Particle Accelerator Conference PAC07 in Albuquerque.
- [2] G. Angelova, et.al., *Installation of the Optical Replica Synthesizer in FLASH*, presented at the 29th Free Electron Laser Conference FEL07 in Novosibirsk.
- [3] V. Ayavazyan, et.al., *Eur. Phys. J. D37* (2006) 297.
- [4] P. Audebert, et.al., *TESLA XFEL: The first stage of the X-ray laser laboratory*, Tech. Design Report, DESY 2002-167.
- [5] The LCLS Design Study Group, *LCLS Design Study Report*, SLAC-R-593, 2002.
- [6] O. Grimm et al., *Longitudinal bunch shape diagnostics with coherent radiation in a transverse deflecting cavity in TTF2*, Proceedings of the 2004 FEL conference, 395.
- [7] G. Berden, et al., *Electro-Optic Technique with Improved Time Resolution for Real-Time, Nondestructive, Single-Shot Measurements of Femtosecond Electron Bunch Profiles*, *Phys. Rev. Lett.* 93 (2004) 114802.
- [8] E. Saldin, E. Schneidmiller, M. Yurkov, *A simple method for the determination of the structure of ultrashort relativistic electron bunches*, *Nucl. Inst. and Methods A* 539 (2005) 499.
- [9] R. Trebino, *Frequency Resolved Optical Gating*, Kluwer, Academic, Boston, 2000.
- [10] A. Winter, et.al., *High-precision laser master oscillators for optical timing distribution systems in future light sources*, EPAC 2006, p. 2747.
- [11] J. Rosenzweig, G. Travish, A. Tremaine, *Coherent transition radiation diagnosis of electron beam microbunching*, *Nucl. Instrum. & Methods A* 365, 255 (1995).
- [12] B. Beutner, W. Decking, M. Dohlus, K. Flöttmann, M. Krasilnikov, T. Limberg, Conference proceedings, 22nd Particle Accelerator Conference, 2007, USA
- [13] M. Röhrs, C. Gerth, Holger Schlarb, Proceedings of the 2006 FEL conference, 300.
- [14] G. Angelova, et.al., *Observation of two-dimensional longitudinal-transverse correlations in the electron beam by laser-electron interaction in FLASH*, submitted for publication.