INSTALLATION OF THE OPTICAL REPLICA SYNTHESIZER IN FLASH

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Abstract

During the shutdown in spring 2007 the optical replica synthesizer, a novel device to diagnose ultra-short electron bunches, is assembled in the FLASH accelerator. We report on the status of the construction work with emphasis on the two electro-magnetic undulators needed for micro-bunching and replica-pulse generation.

INTRODUCTION

Monitoring and tuning the bunch size are essential for the reliable operation of linac-based SASE free-electron lasers such as the FLASH [1], XFEL [2], or LCLS [3]. This need has triggered the development of new diagnostic methods based on a transversely deflecting cavity [4] or electro-optical sampling [5]. The optical replica synthesizer (ORS), a complementary scheme that was introduced in Ref. [6], is similar to an optical klystron FEL seeded by an infrared laser as is shown in Fig. 1. In the modulator the interaction of the laser with the transversely oscillating electrons causes an energy modulation. A small chicane turns this energy modulation into a corresponding density modulation at the wavelength of the light. In a following radiator undulator the micro-bunched beam 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 will be analyzed by a commercially available second-harmonic generation FROG (frequency resolved optical gating) device, called GRENOUILLE [7].

During the spring shutdown 2007 most components such as the undulators, external laser building, seed laser transport system, and the optical stations were installed and we report on these activities.

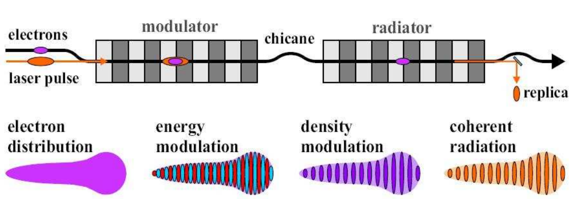

Figure 1: The principle of the optical replica.

UNDULATORS AND CHICANE

The undulators were designed, assembled and tested at Scanditronix Magnet AB, Sweden and were delivered to DESY in March. They have a length of 1450 mm, a width of 454 mm, a height of 817 mm, and weight 480 kg. The gap is 40 mm in order to accommodate the standard 38 mm vacuum pipe without having to break vacuum. The period length is 200 mm with 14 poles and 28 coils connected in 4 separate coil circuits. This allows adjusting the field integrals $I_1 = \int_0^L B(z)dz$ and $I_2 = \int_0^L \int_0^z B(z')dz'dz$ by controlling the end coils in the 1/2, -3/4, +1 pattern. The first and last coil (with 1/4-excitation) have independent supplies and the second and 13th coils are powered in series by another supply. Finally, the ten central coils are connected in series to a fourth power supply. The maximum magnetic field is 0.5 T and nominal field 0.3 T. The undulators can be mounted horizontally or vertically to induce vertical or horizontal beam oscillations, respectively.

Upon arrival at DESY field measurements were performed with a Hall probe and power supply settings were found that zero the field integrals in order to avoid perturbing the electron beam outside the undulator. The individual Hall probe measurements have an accuracy ε of a few Gauss, but the calculation of the first and second field integrals has an accuracy of $\sigma(I_1) = \varepsilon\sqrt{Ldz}$ and $\sigma(I_2) = \varepsilon L\sqrt{Ldz}/\sqrt{3}$ where dz is the distance between consecutive Hall-probe measurements [8]. This allows us to measure the field integrals with an accuracy on the order of 10^{-5} Tm or 10^{-5} Tm^2, respectively, provided we use a small step size of $dz = 2$ mm. We then determined settings of the power supplies for peak fields of 0.1, 0.2,

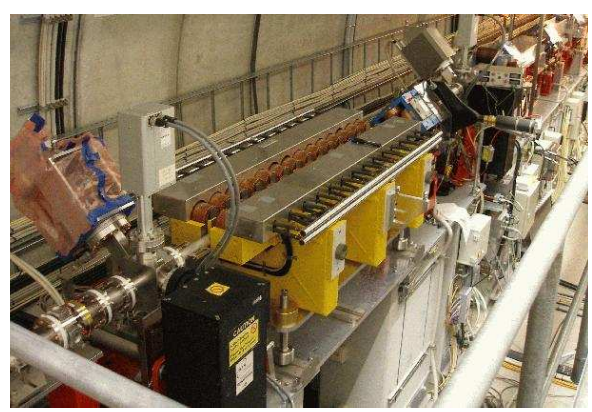

Figure 2: The modulator which causes vertical oscillations.

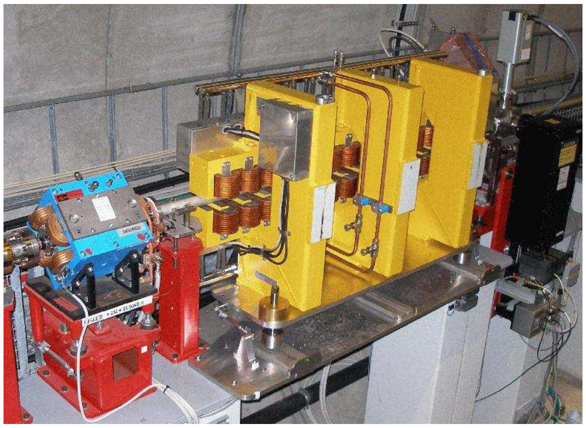

Figure 3: The radiator which causes horizontal oscillations.

0.3, 0.35, 0.4 T for which the field integrals are less than 0.5×10^{-4} Tm and 2×10^{-4} Tm^2. In order to achieve reproducible settings we always cycle the power supplies from zero to the 0.48 T-value, back to zero and then up to the set-value.

After the completed field measurements the undulators were installed in the FLASH beam line after the dog-leg chicane used for momentum collimation. Figure 2 shows the modulator which causes vertical beam oscillations at its final location in the FLASH beam line and Fig. 3 shows the radiator which causes horizontal beam oscillations. This will allow to separate the weak replica pulse from the strong seed laser pulse by polarizers.

The chicane consists of four standard steering dipole magnets which allow a maximum excursion of the beam of 15 mm, thereby producing an R_{56} of 300 μm.

SEED LASER, LASER TRANSPORT AND OPTICAL STATIONS

The seed laser consists of an erbium-fiber oscillator [9], developed at DESY, that can be synchronized to the accelerator-RF. The pulse from the oscillator is frequency-doubled and then fed into a regenerative Ti:Sa amplifier (Clark CPA-2001), based on chirped-pulse amplification and pumped by a Nd:YAG laser. This system, initially prepared at Stockholm University, delivers a pulse output of 0.8 mJ with pulse length of about 170 fs, center frequency 772 nm and 1 kHz repetition rate. The laser will be shipped to DESY in August and then installed in a newly erected 150 m^2 laser building next to the FLASH tunnel. For replica operation the laser stretcher and compressor will be re-tuned to provide about 2 ps pulses and will be synchronized to the beam. The anticipated repetition rate is 5 to 10 Hz. A sketch of the layout along the tunnel is shown in the top of Fig. 4 and a view from above in the lower part of Fig. 4, which shows the 12 m long laser transport system from the laser to the entrance port to the beam vacuum system in the dog-leg chicane. Just before the entrance window a remotely adjustable three-lens telescope will permit adjusting the diameter and the waist position of the laser inside the modulator undulator. The laser transport system was installed and aligned during the recent shutdown.

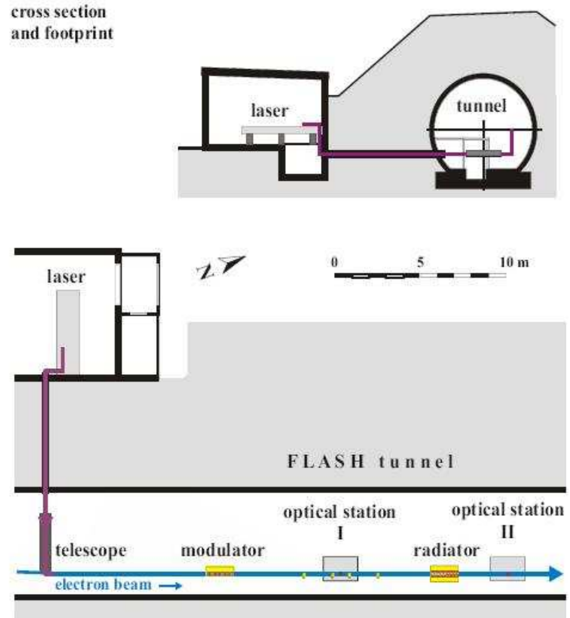

Figure 4: View along the tunnel and top view of the layout of the optical replica synthesizer experiment.

Also indicated in Fig. 4 are two optical stations with optical tables and OTR chambers with a set of different foils that can be viewed by a CCD camera in order to analyze the seed laser or replica pulse and the beam profile. In station I located in the center of the chicane we can image the seed laser, modulator radiation, and the electron beam onto a CCD camera to optimize the spatial overlap of laser and electrons and onto fast photo diodes to optimize the temporal overlap. In station II we will analyze the replica pulse

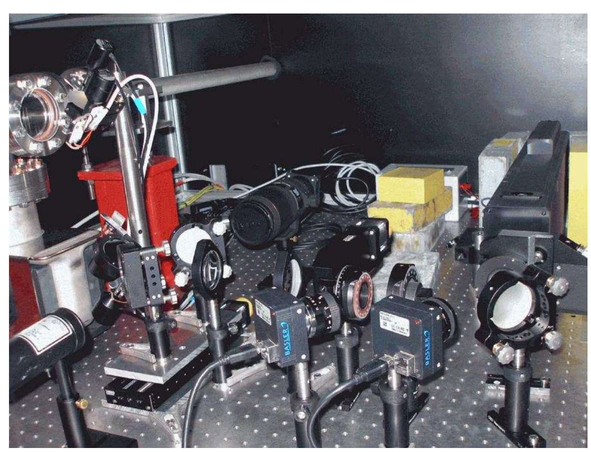

Figure 5: Optical station 2.

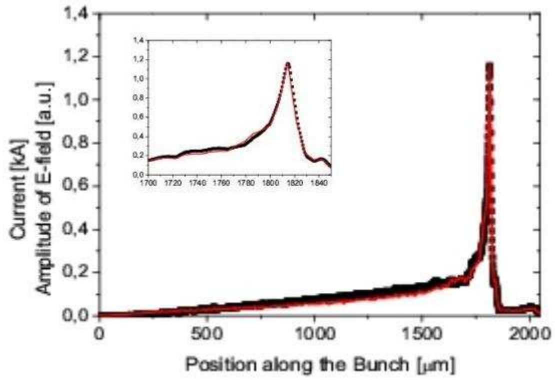

Figure 6: A realistic longitudinal bunch profile (red solid line) and the temporal profile of the emitted replica pulse (black asterisks). The inset figure shows a zoom of the peak region.

generated in the radiator. A picture of optical station II that was installed during the recent shutdown is shown in Fig. 5. At the top of the figure, the beam pipe is visible with the beam moving from right to left. In the top left corner a window from the vacuum tank containing remotely controlled mirrors to extract the replica pulse is visible. The pulse is then vertically deflected by remotely controlled mirrors onto an optical table which contains power meters, fast photo-diodes and the GRENOUILLE [7] that will be used to determine the temporal profile of the replica pulse and thereby the bunch profile. The GRENOUILLE is the black box visible at the right side of Fig. 5.

SIMULATIONS

We perform numerical simulations of the replica process using the Free Electron laser code GENESIS 1.3[10] where the energy modulation in the modulator undulator and the output power from the radiator undulator are calculated. The magnetic chicane is modelled by a transfer matrix. Fig. 6 shows a realistic current profile at the entrance of the modulator determined in start-to-end simulation [11] as the line and the replica pulse as asterisks, both normalized to the same peak value. We observe that the replica pulse faithfully reproduces the initial electron distribution. Simulations, however showed that it is necessary to make the electron beam in the radiator as small and as round as possible in order to achieve the faithful representation, because otherwise diffraction effects of the finite beam size will deteriorate the quality of the reproduction. A slight effect of smearing due to the finite slippage of the electrons with respect to the emitted light is also present, but can easily be de-convoluted, which was, however, not done here.

OUTLOOK

There are 15 shifts alloted for the optical replica synthesizer during September and October when we will start by commissioning the undulators and software to control the beam steering and the beta functions to compensate the weak focusing of the undulators. We then need to verify parasitic operation of the undulators and the chicane during SASE operation. In a second block we will commission the seed laser and optical station I and achieve spatial overlap of laser and electron beam. In a third block of shifts we plan to achieve temporal overlap of seed laser and beam, commission optical station II and eventually record the first FROG traces on the GRENOUILLE.

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