FIRST HEATING WITH THE EUROPEAN XFEL LASER HEATER*

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Abstract

The EU-XFEL laser heater is installed and commissioning phase is ongoing. In this paper I discuss the steps undertaken and report the first heating of electron beams observed in the injector section.

INTRODUCTION

The European XFEL is a 3.4 km long free-electron laser (FEL) which will deliver radiation in the wavelength regime of 0.05 to 4.7 nm. To avoid problems with longitudinal micro bunching instabilities a laser heater is implemented. The interaction region is located in a chicane and consists of a 0.7 m permanent magnet undulator in which IR-laser pulses are overlapping electron bunches during the passage and induces a phase space modulation. When the electron bunches leave the chicane section via two bending magnets the modulation is smeared out and leave a net "heating effect". This in turn increases the overall stability and therefore the overall brightness level of the FEL. The principle has previously been proven [1-2].

The EU-XFEL Laser Heater is a Swedish in kind contribution and has earlier been described in detail [3-5]. In this paper I report the commissioning steps undertaken and the first recorded heating outputs observed in the injector section and finish with a conclusion and outlook.

USER INTERFACE

Most of the Laser Heater features are controlled through the DESY Distributed Object Oriented Control System (DOOCS) control system via the JAVA DOOCS DATA DISPLAY (JDDD) interface [6-7]. The interface displays the laser heater in a schematic way. Each optical station such as the laser laboratory on level 5 in the injector building, optical stations 0 and 1 (OS0 & OS1 close before and after the interaction region on level 7 respectively) can easily be operated separately.

PRECONDITIONING

Given the default electron energy of 130 MeV, a laser wavelength (λ_L) of 1030 nm and the wiggler period (λ_w) of 7.4 cm the undulator gap had to be 42.43 mm to fulfill the known resonance condition :

$$B_w = \frac{2\pi \cdot m_e \cdot c}{q_e \cdot \lambda_w} \cdot \sqrt{2\left(\frac{\lambda_L}{\lambda_w} \cdot 2 \cdot \gamma^2 - 1\right)}$$

The laser pulse was set to 22 ps flattop FWHM for IR (which corresponds to 22 ps for the UV cathode laser as well), laser pulse energy was limited to ~4μJ per pulse at interaction region since the foreseen heater amplifier was not yet installed. Due to preliminary conditions waiting for the amplifier the laser spot size in the interaction region was tuned to σ≈0.6 mm as opposed to the e-beam σ≈0.3 mm.

TRANSVERSE OVERLAP & SETTING THE STAGE

To accomplish heating of the electron bunches overlap of the laser beam has to be assured. The transverse overlap is obtained by reading out the positions on Cromox screens directly before and after the interaction region of the undulator where both, the electron and the laser beams can be observed. The laser beam position is adjusted with the two orthogonal linear stages making up the periscope on OS0. Due to the design the overlap can be adjusted in the X- and Y-direction independently by one translation stage each. An example of illustrated laser spot and, electron beam and laser simultaneously can be seen in Fig. 1.

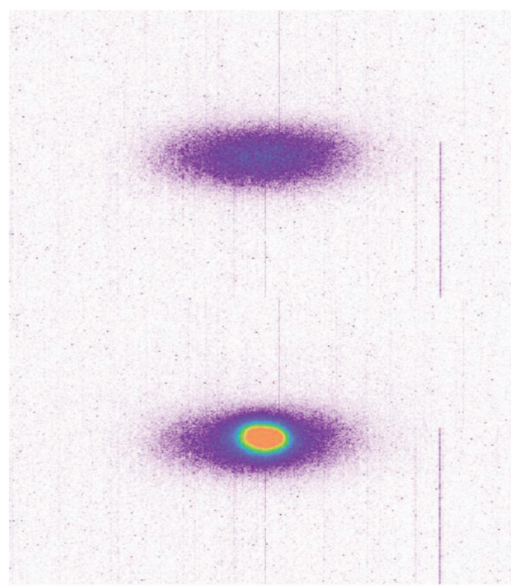

Figure 1: Cromox screen directly before undulator with top only laser, bottom, e-beam and laser illustrating transverse overlap.

TEMPORAL OVERLAP & HEATING

The temporal overlap was first controlled via a rough delay line adjusted by hand and adjusted after read out from a photo diode at the inlet of OS1 after the undulator. A 4 GHz oscilloscope was used to display the signal from the laser and undulator synchrotron light respectively.

Once the course overlap was found a fine delay line based on a retroreflector mounted on a 210 mm motorized linear stage with ~μm resolution was ready for use. Due

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to the travel back and forth the double length is passed which corresponds to an adjustment possibility of up to 1.4 ns which is sufficient for the purpose. The electron bunch and laser pulse length was in the first test set to 22 ps and a reasonable step size for the fine delay line was selected to be ~7 ps corresponding to 200 divisions of the full pathway.

As readout of the heating we choose to illustrate the electron bunch width standard deviation at the dispersive section before the dump of the injector with a screen station. The electron optic was optimized for this measurement in order to get a low beta function and a high dispersion at the place of the screen. The first scan resulted in the spectrum shown in Fig. 2. The extra energy from the heating should result in a net broadening effect which also was discovered at the preset 0 position. Each pixel corresponds to ~1.4 keV energy spread. The observed increase of the energy spread from 14 keV to 18 keV is in agreement with the low laser power at that time.

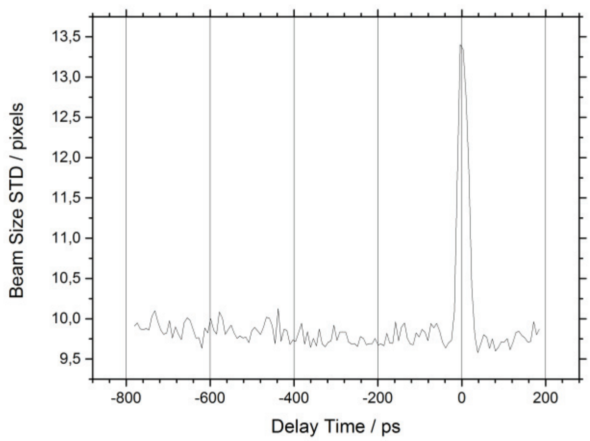

Figure 2: Fine delay line scan illustrating the first sign of heating of the electron bunches by displaying bunch width standard deviation at the dispersive section vs delay line position given in ps.

Subsequently the laser stacker was removed to more than double the peak power. The duration time was still 22 ps FWHM for the IR but instead ~10-12 ps FWHM for the UV pulses going to the electron gun. No strong change in heating effect was observed however.

Investigations while turning on the transverse deflecting structure (TDS) and observing the trace in the dispersive section. This is illustrated in Fig. 3 when the laser is blocked and unblocked respectively. It is clear that the trace is becoming fuzzier during laser overlap i.e. is heated.

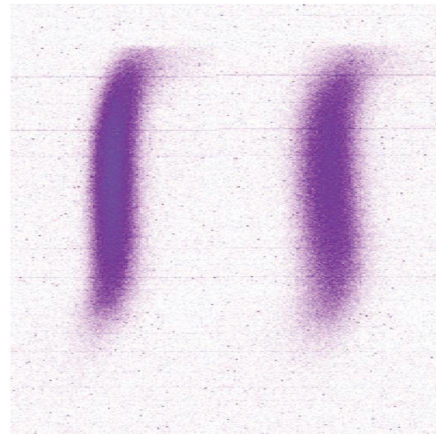

Figure 3: OTR screen in dispersive section after the laser heater and TDS switched on with left, only laser blocked, right, laser unblocked clearly showing a fuzzier trace.

UNDULATOR GAP SCAN

As mentioned the initial undulator setting was chosen to match the 130 MeV e-beam energy and the undulator gap set to 42.4 mm. Gap scans were undertaken showing results displayed in Fig. 4. Where the main resonance is clearly visible.

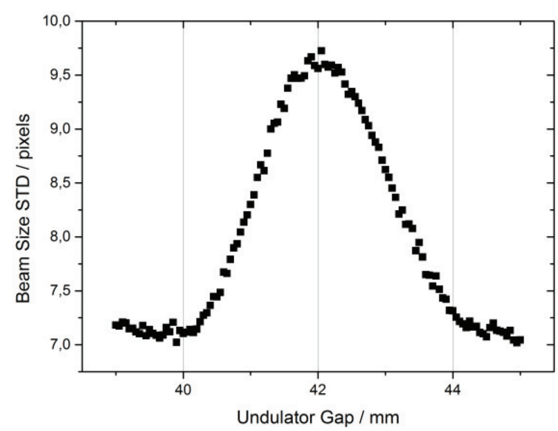

Figure 4: Undulator gap scan versus heating of the electron bunches by displaying bunch width standard deviation in pixels.

The gap scans where repeated at different energies. The gaps where the resonances were found a shown in Fig. 5 together with the theoretical values. The observed offset of about 0.3% in energy is well within the precision of the energy measurement.

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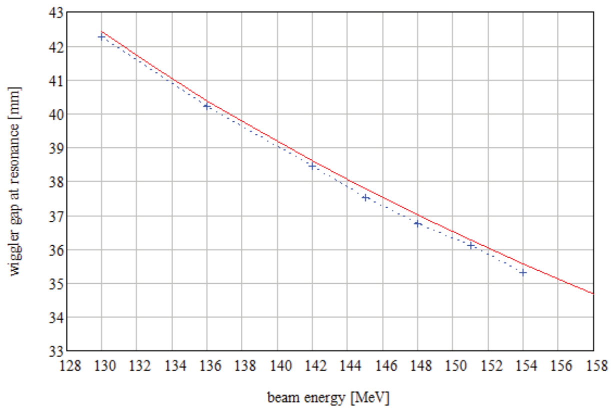

Figure 5: Measured and theoretical undulator / wiggler gap vs. beam energy.

ATTENUATOR SCAN

Also the limited laser energy of ~4 µJ inside of the interaction region was scanned for optimization using a λ/2 plate in a stepper motor driven rotation stage and with a subsequent polarization dependent beam splitter cube. The limited energy does not indicate any obvious resonance as can be seen in Fig. 6.

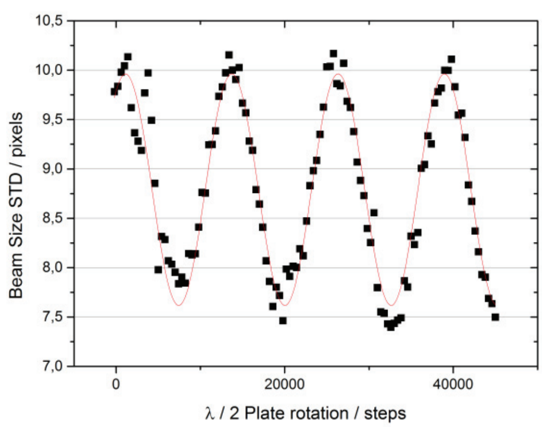

Figure 6: Laser energy scan by rotating λ/2 plate before polarization dependant beam splitter cube.

CONCLUSION AND OUTLOOK

It is clear that the EU-XFEL laser heater is demonstrating heating.

Currently the commissioning is ongoing with implementation of a laser amplifier able to produce energies over 200 µJ per pulse [8]. This also implies undertaking minor adaptations due to the change of length and optimization of the incoming laser beam for the laser heater to run under the specified beam conditions. Additional foreseen adaptations include a simplified laser width adjusting routine. For the 4D laser routing and stabilization system mentioned as the worlds most advanced, an automatized attenuation system is implemented to optimize the power levels on the position sensitive detectors in the system. It is also foreseen to if needed use the 4D system as a fast scale delay line to adopt for temporal drifts on picosecond scale. Such drifts could be monitored by a cross correlator possibly based on two photon-absorption. Additionally, the mirrors inside of the UHV section are chosen to be of metal to avoid beam disturbance. They should be recoated with an amorphous gold coating completely without grain structure or crystallinity to increase the laser damage threshold further.

Next commissioning step will be to redo the laser-electron beam interaction measurements in the injector section with the higher energies from the amplifier and optimized specs. This will also be compared in detail with theoretical calculations.

Finally, a full commissioning investigating the impact on the EU-XFEL SASE will be undertaken and is foreseen in 2017.

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