COMMISSIONING AND FIRST HEATING WITH THE EUROPEAN XFEL LASER HEATER*

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Abstract
The Laser Heater of the European XFEL has been installed and commissioning is in progress. We discuss the setup and the results of the first electron beam heating in the injector section.

INTRODUCTION

The 3.4 km long European X-ray Free Electron Laser (XFEL) is in the commissioning phase. It will deliver high brilliance hard X-ray flashes within the wavelength regime of 0.05-4.7 nm.

A plausible problem with FEL's is longitudinal micro bunching instabilities who hampers the outgoing radiation power. A proven way to overcome such effects is to implement a Laser Heater where a phase space modulation is created by a laser overlapping the electron bunches in resonant condition while passing an 0.7 m undulator inside of a dipole magnet chicane section. The phase space modulation effect is smeared out to a stabilizing net heating effect of the electron bunches as they are passing the second dogleg of the chicane [1-2].

The Laser Heater of the EU-XFEL is a Swedish in kind contribution and has previously been described in detail [3-6]. We report here about the ongoing commissioning, undertaken steps before concluding the status and give an outlook about the future.

PRECONDITIONING

To fulfill the resonance condition with the laser wavelength (λ_L) of 1030 nm, wiggler period (λ_w) of 7.4 cm and electron energy of 130 MeV the undulator gap was tuned to 42.4 mm according to:

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

The laser pulse was set to ~22 ps flattop FWHM for the UV cathode laser and the IR laser then was ~25 ps. They are temporally locked and derive from the same oscillator. The amplifier was not yet installed during the first run which limited the laser energy to ~4 µJ per pulse inside of the undulator. This was also the reason why the laser was tuned to σ≈0.6 mm instead of σ≈0.3 mm as the e-beam.

OVERLAP TUNING

As a first step to accomplish a full overlap of the laser beam over the e-beam it is natural to start with the transverse position. We used the Cromox screens installed directly before and after the Laser Heater undulator and their ability to independently and simultaneously illustrate both laser and e-beam position. The position of the laser can independently be adjusted in X- and Y-direction by two orthogonal linear stages controlling the mirror positions of the periscope in front of the inlet. Figure 1 below show readout from a Cromox screen with only laser as well as laser and e-beam together. After adjusting the periscope and reading out the upstream and downstream Cromox screen iteratively the transverse overlap was accomplished over the whole interaction section.

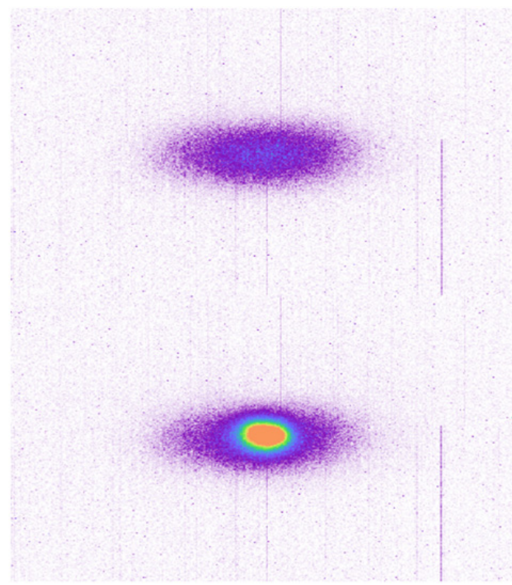

Figure 1: Readout from Cromox screen installed directly upstream of the interaction region with laser only (top). The image below illustrates simultaneous e-beam and laser readout and transverse overlap.

The length of the laser section from source to interaction region is ~50 m. This is different compared to the temporally locked cathode laser beamline. A fixed course and motorized fine delay line was therefore implemented in the laser beamline. The course delay line was adjusted after reading out of a downstream photo diode with a 4 GHz oscilloscope. The signals derived from the attenuated laser signal as well as the synchrotron light emitted by electron bunches passing the undulator, and the delay line was adjusted until the signals was fully overlapping. The resolution was limited to <1 ns by the rise time of the photo diode and bandwidth of the oscilloscope.

The fine delay line is made up by a retroreflector installed on top of a 210 mm (~µm resolution) stepper motor driven linear stage corresponding to 1.4 ns range when taking into account passing the stretch twice.

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HEATING

A good indicator of heating of the electron bunches is the increase of width in a downstream dispersive section. We therefore read out the standard deviation bunch width with an OTR screen in the dispersive section before the injector dump. To increase the resolution, the accelerator optics was tuned for high dispersion at the screen location.

Scanning the fine delay line starting from one side showed that the first registered heating occurred at the default 0 position. This is indicated by the peak in Fig. 2 illustrating how the STD width thanks to the low laser pulse energy changed from ~10 to ~13 pixels corresponding to an increase in energy spread from 14 keV to 18 keV.

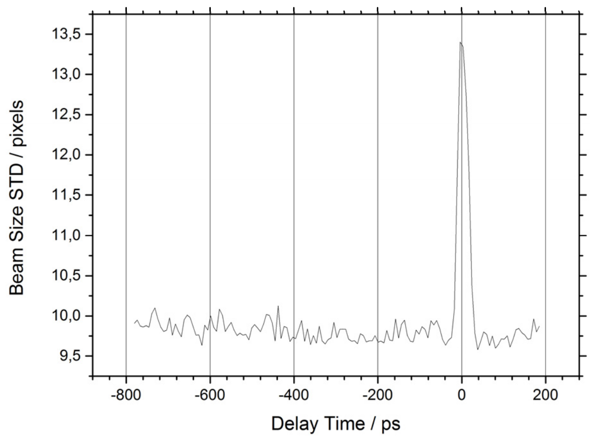

Figure 2: The first fine delay scan illustrating the beam size standard deviation in pixels versus temporal delay in ps relative the cathode laser.

In an attempt to increase the laser heating effect by increasing the laser peak power a pulse stacker was removed. The pulse time was decreased to ~10-12 ps for the cathode laser and close to unaffected for the IR laser. No alteration in the heating was observed.

To illustrate the heating of the bunches the transverse deflecting structure (TDS) was used (Fig. 3). The vertical axis corresponds to the longitudinal direction of the electron bunch whereas the horizontal axis corresponds to the energy spread at that position. It is clear that from the image that the bunch has an increased energy spread.

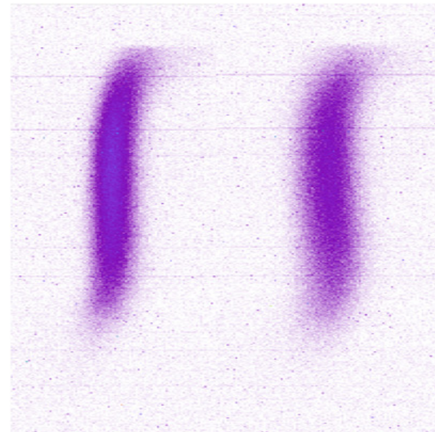

Figure 3: Readout of TDS trace from OTR screen in the dispersive section before the dump when the laser is off (left) and on respectively (right).

UNDULATOR GAP SCAN

As described in the preconditioning section the undulator gap was initially set to 42.4 mm to match the energy of 130 MeV. Scanning the gap from 39 to 45 mm as seen in Fig. 4 shows a large resonance centered around ~42 mm.

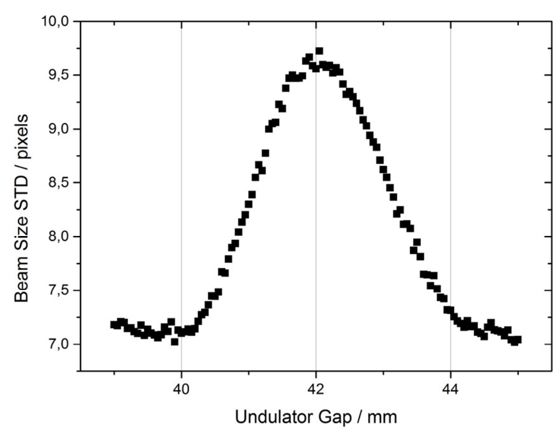

Figure 4: Beam size standard deviation versus undulator gap scan.

The electron beam was tuned to energies ranging from 130 to 154 MeV. The optimal undulator gap settings are plotted together to theoretical calculations (Fig. 5) showing a 0.3% difference and therefore within the error bars of the energy measurement.

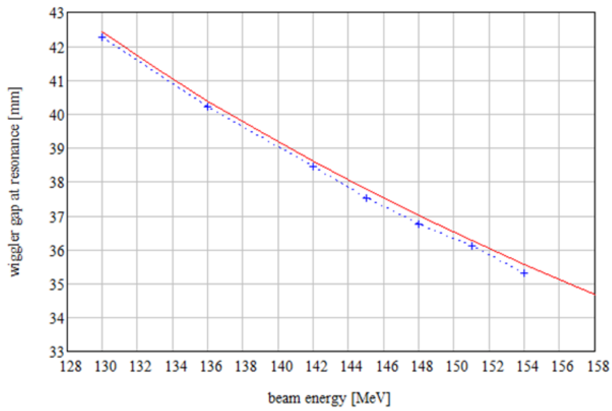

Figure 5: The measured optimal undulator gap setting obtained after an individual gap scan versus e-beam energy.

CONCLUSION AND OUTLOOK

EU-XFEL Laser Heater has demonstrated heating in the injector section and the commissioning is on a good way.

The system is further optimized by implementation of an amplifier for the IR laser increasing the maximum pulse energy to ~200 µJ [7]. More optimizations include the IR laser width at the interaction region. It was also noted that the internal vacuum flanges holding the metal mirrors in the interaction section was rotated with the result of that the mirrors were translated ~10 mm in towards the e-beam. The attenuation system is improved to quickly protect the position sensitive detectors (PSDs) used for the laser stabilization system.

In the upcoming commissioning steps a more detailed power scan will be made to a) investigate if any trickle heating effect is appearing b) clearly illustrate the ability of strong heating with high laser energies. Of utmost interest is also investigation of the overall impact of the laser heater on the EU-XFEL SASE, its stability and power yield.

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