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ELECTRON BEAM HEATING WITH THE EUROPEAN XFEL LASER HEATER*

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Abstract

The Laser Heater of the European XFEL is installed and is in commissioning phase. In this paper, results of heating in the injector section with an additional laser amplifier is discussed.

INTRODUCTION

The European X-ray Free Electron laser (EU-XFEL) will produce fs photon flashes in the interval of 0.05 to 4.7 nm. The setup is based on a 3.4-km long electron accelerator. Longitudinal micro bunch instabilities may occur in the electron beam and hamper the X-ray power level [1]. To overcome such problems a Laser Heater (LH) is installed as in LCLS and FERMI [2-3]. In the LH, a NIR laser is overlapping the electron bunches when they pass a 0.7-m magnetic undulator situated in a chicane section 23-m downstream of the electron gun. The undulator is tuned to resonance which cause a phase space modulation which subsequently is transferred into a net heating effect while leaving the chicane. This heating decreases the instability effects without hampering the FEL performance.

The EU-XFEL LH is a Swedish in-kind contribution which previously has been described [4-8]. Here we report results of injector section measurements after implementation of a NIR laser amplifier [9].

PRECONDITIONING

As described in ref. 6 and 7 overlap of the NIR laser over the electron beam was created in transverse direction in an iterative procedure by readout from Cromox screens. The temporal overlap was adjusted by a fine delay line made up by moving a retro reflector installed on a µm resolution 210 mm linear stage and simultaneously observing heating of the electron bunches as increase in beam width in the dispersive dump section at the injector with an Lyso screen. The accelerator optics was optimized for large dispersion and small beta function at the Lyso screen location to increase the resolution.

The undulator gap was tuned to 42.4 mm to fulfill the resonance condition at the electron energy of 130 MeV with a NIR laser wavelength of (λ_L) of 1030 nm and undulator period (λ_u) of 7.4 cm according to:

$$B_u = \frac{2\pi \cdot m_e \cdot c}{q_e \cdot \lambda_u} \cdot \sqrt{2\left(\frac{\lambda_L}{\lambda_u} \cdot 2 \cdot \gamma^2 - 1\right)}\,.$$

A NIR laser amplifier was installed [9], increasing the NIR laser energy from ~4 µJ to a maximum of ~200 µJ per pulse inside of the undulator. The standard deviation radius of the electron and laser beams were both tuned to approximately σ ≈ 0.3 mm whereas the temporal FWHM of the UV cathode laser and LH NIR laser was tuned to ~12 ps and ~36 ps, respectively. Since they derive from the same oscillator they are inherently temporally locked.

HEATING

As in previous tests the temporal overlap was adjusted through scan of a linear stage made by a ~um stepsize linear stage with an implemented retro reflector and simultaneous readout of the STD beam width on the downstream Lyso screen in the dispersive section. Such measurement is illustrated in Fig. 1 when using a NIR pulse energy of ~35 µJ. The horizontal axis corresponds to temporal offset whereas the vertical axis indicates the STD beam width in mm increasing from 150 µm to 325 µm which corresponds to an energy spread increase from ~11 keV to ~31 keV. This should be compared to previous results without amplifier (and therefore a limited NIR pulse energy of ~4 µJ) of ~14 keV to ~18 keV [8].

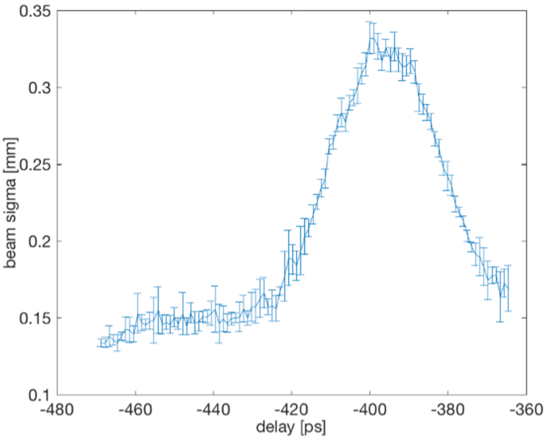

Figure 1: The fine delay scan illustrating the beam size standard deviation in mm versus temporal delay of the cathode laser relative to the beam.

Furthermore, the transverse deflecting structure (TDS) was used to illustrate the effect of the heating. The vertical direction corresponds to longitudinal direction of the electron bunch whereas the horizontal direction corresponds to the energy and therefore illustrate the energy spread at each part of the bunch. An example can be seen in Fig. 2 where the NIR laser is off (top) and partly overlapping (bottom) respectively. It is clear that the whole bunch is strongly heated. The upper part of the heated (bottom figure) bunch is more heated than the lower part.

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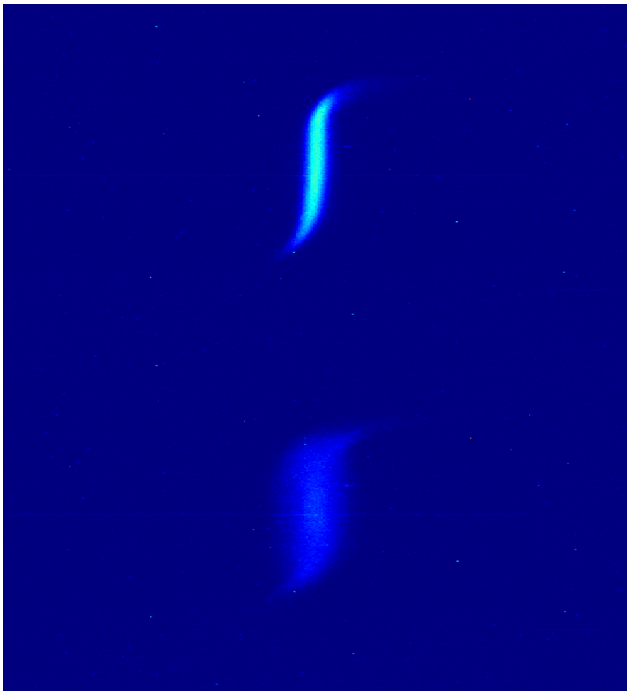

Figure 2: Readout of TDS trace from OTR screen in the dispersive section before the dump when the NIR laser is off (top) and partly temporally overlapping respectively (bottom).

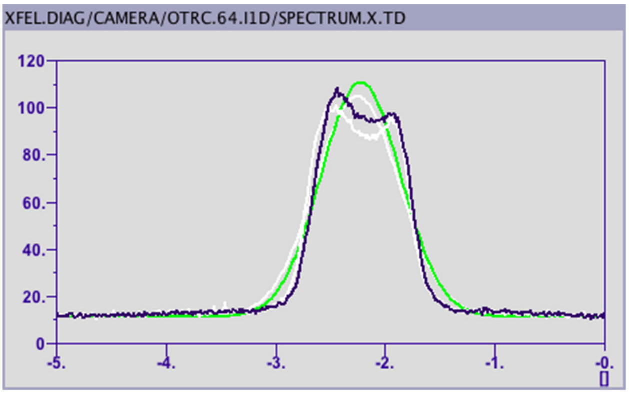

Figure 3: The horizontal projection of the screen intensity in the dispersive section indicating that the energy of the electrons is shifted to higher and lower energies by the LH as predicted for a matched laser beam.

Additionally, the heating effect is illustrated in Fig. 3 indicating that the electron beam is divided into two beams at the dispersive section thanks to the LH accelerating / decelerating part of the electrons respectively, when the NIR laser is fully overlapping with matched beams and on full energy at ~200 μJ.

CONCLUSION AND OUTLOOK

The EU-XFEL Laser Heater demonstrated heating with the additional NIR laser amplifier implemented. The measurements were conducted in the injector section.

The upcoming test will be investigation of the impact of the laser heater on the EU-XFEL SASE, power and stability. Additionally, the following tests will include a fine scan of the power level which will be conducted to reveal any trickle heating effects. Of interest is also to further investigate the heating effect of longer bunches.

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