CONTROL OF THE SEEDED FEL PULSE DURATION USING LASER HEATER PULSE SHAPING *

V. Grattoni†,1, E. Roussel, E. Allaria, S. Di Mitri, L. Giannessi, E. Ferrari, P. Sigalotti, G. Penco, M. Veronese, L. Badano, M. Trovo', S. Spampinati, A. Demidovich, M. Danailov,
Elettra Sincrotrone Trieste S.C.p.A., 34149 Basovizza, Italy
[1]also Dept. of Physics, University of Trieste, Trieste, Italy

Abstract

New Free-Electron Laser facilities deliver VUV – X-ray radiation with pulse length in the range of hundreds and tens of fs. A further reduction of the FEL pulse length is desired by those experiments aiming at probing ultra-fast phenomena. Unlike SASE FEL, where the pulse duration is mainly driven by the electron bunch duration, in a seeded FEL the pulse duration can be determined by the seed laser properties.

The use of techniques able to locally deteriorate the electron beam properties such as emittance or energy spread have been used in SASE FELs to reduce the region of the electron beam that is able to produce FEL radiation and hence reduce the FEL pulse length.

The temporal shaping of the laser heater can be used to create an electron beam characterized by a very large energy spread all along the bunch except for a small region.

We report measurements of the effect of the laser heater shaping on the electron beam phase-space performed at FERMI. Impact on the final FEL pulse properties are predicted with a series of numerical simulations.

TEMPORAL SHAPING OF THE LASER HEATER

FERMI linac (Fig.1) is equipped with a laser heater (LH) system in the injector part that is normally used for suppressing microbunching instability [1] by increasing the electron beam energy spread. During normal operations, the LH laser is characterized by a longitudinal pulse with a Gaussian profile that is significantly longer than the electron beam allowing a uniform heating of the e-beam.

A recent experiment performed at LCLS [2] has shown the possibility to control the FEL pulse duration by acting on the energy spread profile of the electron beam through a proper shaping of the LH laser pulse.

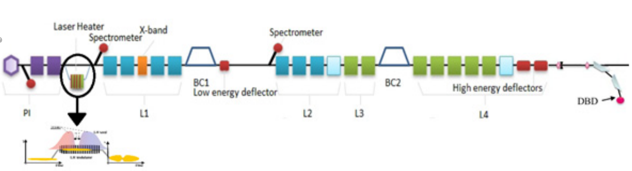

Figure 1: Layout of the FERMI linac including the laser heater (LH). For the experiment a special shaping of the LH laser has been done.

† vgrattoni@gmail.com

We properly modified the LH laser in order to test this capability at FERMI. We have obtained the desired intensity profile of the LH laser pulse (characterized by a hole in the intensity profile) using a pulse shaping setup [3]. The laser pulse is first negatively chirped by a double pass diffraction grating based Treacy-type compressor to a duration of about 7 ps rms. The amplitude shaping is then performed in a 4-f system, where an amplitude mask (a calibrated tungsten wire) is positioned in the Fourier-plane. The width and position of the hole, also called cold zone, in the pulse can be controlled by the width and position of the wire. The obtained laser profile is reported in Fig. 2.

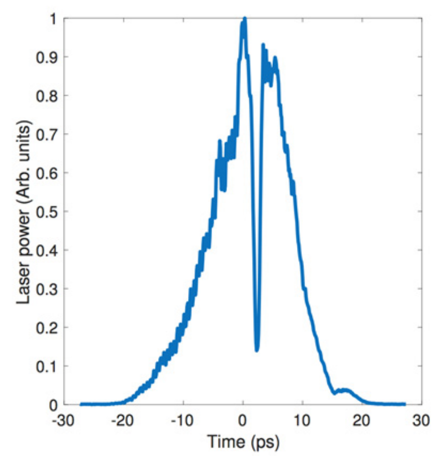

Figure 2: Cross correlation measurement of the LH laser pulse with the temporal shaping. The pulse is characterized by narrow region with low power.

The interaction of the intensity-shaped laser with the electron bunch inside the LH undulator allows the generation of an electron-beam energy-spread profile whose temporal properties mimic the one of the LH laser. In particular the beam will be characterized by a large energy spread except a small region where the energy spread is small.

Controlling the energy-spread profile is important for FEL pulse length since the FEL process critically depends on the energy spread. With a proper adjustment of the LH laser power it is possible to inhibit FEL emission from all the electrons except from those in the narrow central part. This has allowed the Authors of [2] to shorten the FEL pulses at LCLS down to few fs.

The method takes advantage of the compression of the beam occurring in BC1 downstream the laser heater (Fig. 1). In the case of FERMI this would allow to produce pulses of the order of tens of fs by imposing a shape in the beam of the order of hundreds of fs (compression factor ~10).

PRELIMINARY EXPERIMENT

We have performed preliminary experiments in order to verify the efficiency of the energy-spread profile control by means of the LH laser longitudinal intensity shaping.

In this experiment the LH laser shape as reported in Fig.2 has been used. The experiment has been done for the standard FERMI electron beam consisting of 700 pC with a bunch length of 8 ps at the gun compressed to less than 1 ps at the linac end, with final energy of 1.4 GeV.

In the LH the shaped LH laser interacts with the electron bunch and after the compression the low energy spread region is expected to measure about 100 fs.

The effect of the shaped LH laser has been measured acquiring the images of the electron beam phase space at the end of the linac in the diagnostics beam dump (DBD) area (Fig.1). In DBD the energy dispersion on the horizontal axis of the bending is combined to the vertical deflection of an RF deflector that converts temporal coordinates in vertical positions. As a result images of the e-beam passing through a YAG:Ce scintillating screen can provide information on the electron beam phase-space.

Figure 3 shows an example of the longitudinal phase-space (the image has been rotated with respect to the original to have the temporal axis on the horizontal direction). From the phase-space image it is possible to determine the evolution of the electron beam current, energy and energy spread along the pulse (Fig.3 b and c).

From the data reported in Fig.3a it can be seen that in the region around t = 0 there is a smaller energy spread and an higher electron beam density that characterize the effect of the shape imposed to LH laser. Since the result is not immediately clear and it could be masked by phase-space distortions on the electron beam, we acquired a long sequence of data where the delay between the LH laser and the electron beam is changed continuously, so that the hole in the LH laser passes across the beam.

We have collected 260 images, by changing the position of the LH laser along the electron from -12.5ps to +12.5 ps with 26 steps and acquiring 10 images at each LH laser timing. For each image we have calculated the mean slice energy, slice energy spread and current profile. After correcting the images for the temporal jitter, we calculated the average energy spread profile for each of the 26 values of the LH laser delay. After having removed the energy spread profile for the unheated beam, these 26 traces have been used to create the false color map in Fig. 4 that represents a measure of the profile of the LH induced heating along the beam (vertical axis) as a function of the LH laser delay (horizontal axis).

Our measurements clearly show the evidence of a cold region in the electron beam that shifts along the beam as the delay between the LH laser and the beam is scanned. The data reported in Fig. 3 refer to the line corresponding to t = 0 in Fig. 4.

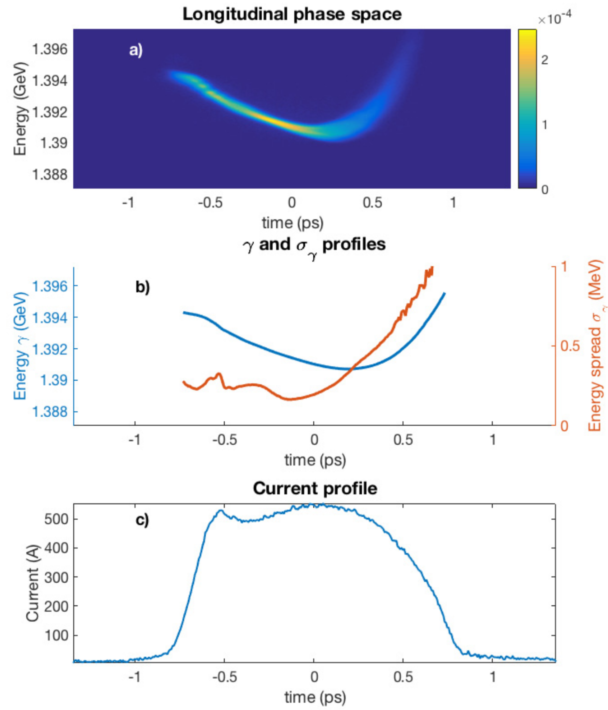

Figure 3: a) Longitudinal phase space of the electron bunch collected in the DBD. b) Slice energy and slice energy spread of the electron bunch. c) Current profile of the electron bunch.

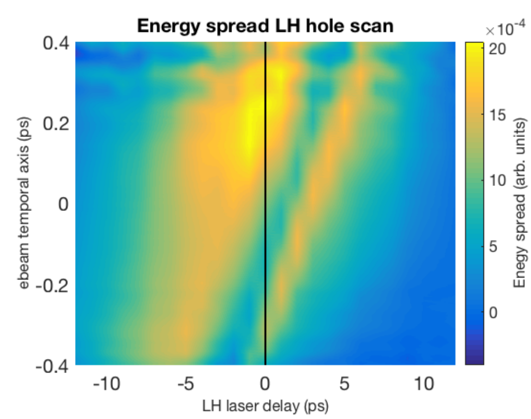

Figure 4: False colour plot representing the slice energy spread (in false color) produced by the LH laser as a function of the delay with respect to the electron beam (hor. axis).

RESULTS FROM SIMULATIONS

In order to estimate the effect of a controlled energy spread profile to the FEL pulse length, we performed a series of FEL simulation with the FEL code GINGER [4]. Simulations used an electron beam with standard electron beam parameters for FERMI with a profile of the energy spread that has been changed to mimic the effect of the shape produced by the LH laser [3] with a short cold region in an otherwise very large energy spread. For our

ISBN 978-3-95450-182-3

studies we used for the energy spread of the central part of the electron bunch, 150 keV that corresponds to the nominal FERMI energy spread and also gives its best performance [5]. For the rest of the beam an energy spread of 900 keV has been used that is sufficient to suppress the FEL gain.

Various simulations have been done by varying the width of the cold region in the beam from 70 fs to 4 fs in FWHM (Fig. 5).

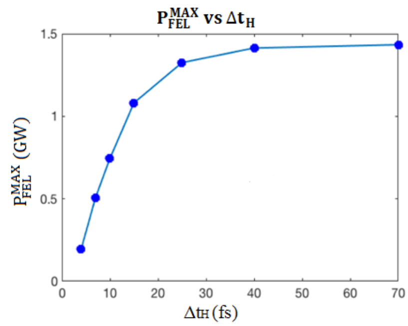

Figure 5: Peak power of the FEL pulse obtained from simulations as a function of the duration of the low energy spread region of the electron bunch in FWHM.

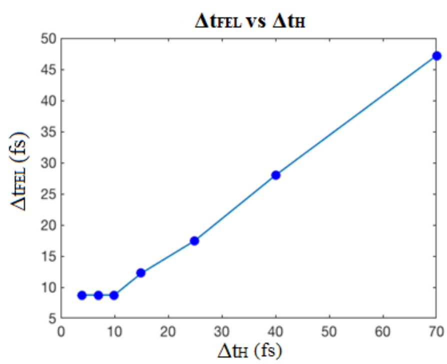

Figure 6: Duration of the FEL pulse in FWHM as a function of the duration of the low energy spread region of the electron bunch in FWHM.

For our studies we focused at FERMI FEL-1 operated at 26 nm. For each configuration an optimization has been done and the FEL pulse energy and length have been obtained. Our results reported in Fig. 5 and Fig. 6 give the evidence that we can obtain a peak power of almost 1 GW for a pulse with FWHM of 10 fs (Fig. 6). Below 10 fs we observe a saturation of pulse length reduction due to the slippage inside the radiator. In order to overcome this limit that is related to the FEL wavelength and the undulator parameters, it is possible to operate the FEL in the coherent harmonic radiation regime by considering just the emission from the first undulator of the radiator. In this case our simulation results show that it is possible to produce pulses down to 4 fs, although with reduced peak power.

CONCLUSION

We reported the results of our studies aiming at the generation of short FEL pulses at FERMI using the longitudinal shaping of the intensity at the laser heater. Simulations show that by controlling the energy spread profile in the laser heater it is possible to generate pulses of about 10 fs at FERMI FEL-1. Preliminary experimental results show that the desired energy spread profile can be transferred from the laser of the laser heater system to the electron beam. Studies will continue for demonstrating the generation of short pulses at FERMI.

ACKNOWLEDGEMENT

Authors acknowledge the support and useful discussion with the FERMI team. V. Grattoni is grateful to Prof. F. Parmigiani for support and useful discussions.

REFERENCES

[1] S. Spampinati at al., “Laser heater commissioning at an externally seeded free-electron laser”, Phys. Rev. ST Accel. Beams 17, 120705 (2014).

[2] A. Marinelli et al., “Optical Shaping of X-Ray Free-Electron Lasers”. Phys. Rev. Lett. 116, 254801 (2016).

[3] V. Grattoni, “Study for the Generation of Ultrashort Pulses in a Seeded FEL” Universtiyt of Trieste master thesis (2017).

[4] W.M. Fawley, LBNL CBP Tech Note-104 (1995).

[5] E. Allaria et al., “The FERMI free-electron lasers”, Journal of Synchrotron Radiation 22, 485 – 491 (2015).