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NON-STANDARD USE OF LASER HEATER FOR FEL CONTROL AND THZ GENERATION

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Abstract

The laser heater system is currently used at various FEL facilities for an accurate control of the electron beam energy spread in order to suppress the micro-bunching instabilities that can develop in high brightness electron beams. More recently, studies and experiments have shown that laser-electron interaction developing in the laser heater can open new possibilities for tailoring the electron beam properties to meet special requirements. A suitable time-shaping of the laser heater pulse opened the door to the generation of (tens of) femtosecond-long FEL pulses.

Using standard laser techniques it is also possible to imprint onto the electron bunch, energy and density modulations in the THz frequency range that, properly sustained through the accelerator, can be exploited for generation of coherent THz radiation at GeV beam energies.

In this report, recent results at the FERMI FEL are presented together with near future plans.

INTRODUCTION

Modern linear accelerators that opened the era of X-ray Free Electron Lasers (X-FELs) [1–5] are required to generate very high peak current and high-quality electron beams in order for them to sustain the FEL process. The high peak current is generally achieved with the compression of the electron bunch in magnetic chicanes. Due to the very high density that electrons reach in the 6-D phase space, the beam develops collective effects, such as the microbunch instability, that can deteriorate the electron beam properties [7]. This instability can be driven by longitudinal space charge (LSC) [8] and coherent synchrotron radiation (CSR) [9]. These instabilities can introduce into the electron beam very strong energy modulations [10] that are a limitation for the operation of X-FELs at short wavelengths and in particular for seeded FELs because they produce a reduction of the longitudinal coherence [11, 12].

In order to fight the development of the microbunch instability, the so-called laser heater (LH) has been proposed [7] and is currently used in most FELs [13,14]. By using a resonant interaction between the electron beam and an external laser, the LH introduces a controlled spread in energy of the uncompressed beam and at low energy. This process can be optimized to suppress the microbunch instability [7]. As a result of the LH, the FEL intensity can be increased significantly [13,14]. In addition, specifically for seeded FELs, it has been shown that the LH is essential to produce narrow-bandwidth FEL radiation [11,12].

NON-GAUSSIAN ENERGY DISTRIBUTION

The optical energy modulation introduced to the beam by the interaction with the laser is removed by the LH chicane who is designed to smear out short wavelength modulations. This lead to an uncorrelated energy spread on the beam. It has been shown that the shape of distribution of the energy spread can be controlled acting on the relative transverse size of the laser and electron beam in the interaction region [13]. In particular the use of a laser with a transverse mode significantly larger than the electron beam can lead to distributions that differ significantly from a Gaussian and can become a double horn distribution [15].

Having the possibility to control the shape of the electron energy distribution is important in the case of seeded FELs. Indeed, the use of non-Gaussian distributions can lead to a more efficient bunching process at higher harmonics.

Figure 1 reports the results of numerical simulations showing the advantage of using a non-Gaussian distribution for wavelengths shorter than 16 nm. For details about the parameters in the simulations refer to [16].

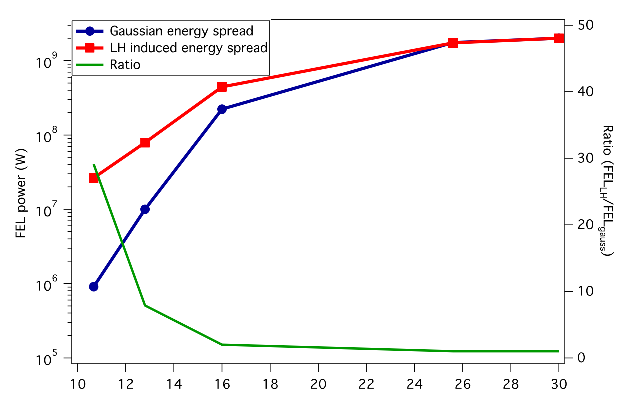

Figure 1: Simulations results of FEL power vs wavelength for standard Gaussian energy spread and LH induced non-Gaussian energy spread [16].

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TEMPORAL SHAPE CONTROL

For standard operation modes LH has a laser pulse that is much longer than the electron beam. This allows producing a uniform energy spread along the whole beam that can be entirely used for generating FEL radiation. However it is possible to control the energy-spread profile by acting on the temporal shape of the LH laser. This possibility can be exploited to control the shape of the FEL pulse length since the FEL process critically depends on the energy spread. This optical shaping of the e-beam [17] has been proposed as an alternative scheme to the emittances spoiler used at SLAC for shortening the FEL pulse [18].

A preliminary experiment has been performed at FERMI for controlling the temporal shape of the electron beam energy spread [18]. The laser pulse has been temporally shaped as reported in Fig. 2 by chirping the laser pulse and using a 4-f system, where an amplitude mask is placed in the Fourier-plane.

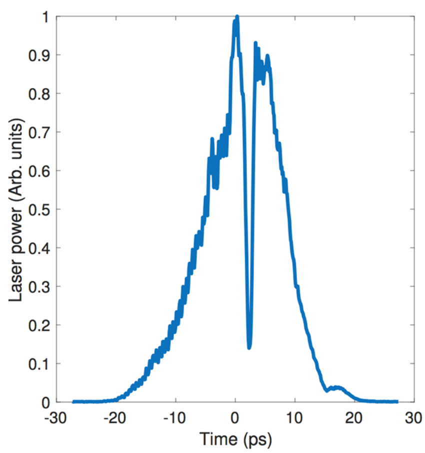

Figure 2: Cross correlation curve of the LH laser pulse with the temporal shaping. A narrow region in the centre of the pulse is characterized by low intensity.

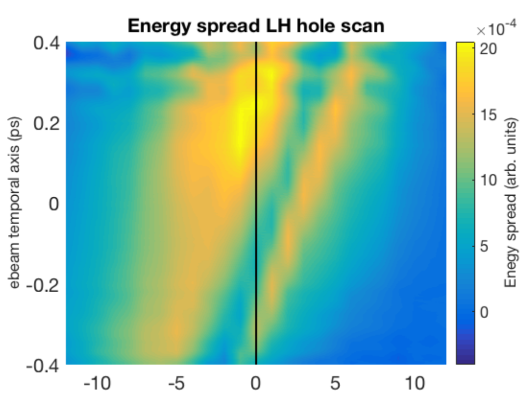

Figure 3: False colour plot representing the slice energy spread produced by the LH laser as a function of the laser delay with respect to the electron beam.

The shaped laser has been used in LH and the beam compressed and propagated as usual [19] to the end of the linac. There a transverse deflecting cavity has been used to measure the slice energy spread.

Figure 3 reports the result of the measurements of the electron-beam slice energy-spread along the beam axis (vertical axis) as the delay between e-beam and the laser has been changed (horizontal axis). Data clearly show the presence of a cold region of the beam that moves as the relative delay is changed.

A future upgrade in the transport system for the LH laser will be used for a sharper profile that combined with the seeding would allow the generation at FERMI FEL pulses at the 20-nm spectral range as short as 10 fs [18].

LONG WAVELENGTH PERIODIC MODULATION

An additional possibility is to introduce in the LH laser an amplitude modulation at much longer wavelength than the optical one. This has been done by taking advantage that the LH laser is generally strongly chirped. The superposition of two chirped laser pulses produced a pulse with a strong amplitude modulation that depends on the relative delay (Fig. 4) [19].

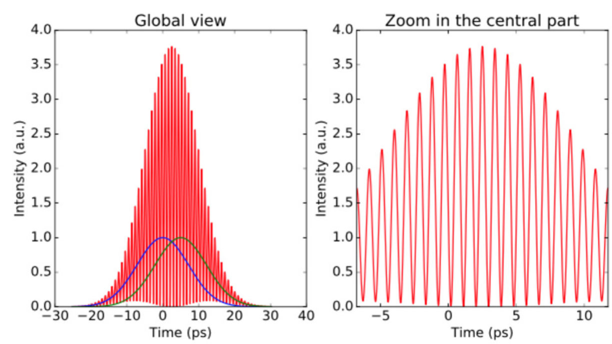

Figure 4: Amplitude modulated laser pulse obtained with the beating from two chirped pulses with a small relative delay.

It has been shown at FERMI that this long wavelength modulation can be transferred to the electron beam as energy spread amplitude modulation and it is not washed out by the LH chicane. The laser beating wavelength can be adjusted to enter the gain bandwidth of the micro-bunching instability, so that the small modulation introduced into the beam in the LH can be amplified trough the accelerator and create significant energy and current modulation to the beam. Those modulations can be controlled to be in the few-THz frequency range.

This seeded micro-bunching gives the possibility to control electron beam properties that can be exploited for special FEL operational modes or for coherent THz emission.

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CONCLUSION

We discussed new interesting possibilities offered by the laser heater for controlling specific properties of the electron beam. Results already obtained at FERMI and new planned experiments have been presented.

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