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Single shot temporal characterization of FEL Pulses

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Since the free-electron laser FLASH at DESY in Hamburg, [1] lases in Self-Amplified Spontaneous Emission (SASE) mode each pulse is "unique"and has different pulse energy, spectrum, arrival time and pulse duration. A Terahertz (THz) field driven streak camera [2,3] has the potential to deliver single-shot pulse duration information basically wavelength independent and with a high dynamic range (in pulse duration and FEL energy) and it is able to be operated with repetition rates up to several hundred kHz (potentially even MHz). In addition, it can provide arrival time information between the XUV pulse and the laser driving the THz generation for each single pulse with accuracy well below 10 fs resolution.
The measurement principle is based on a noble gas target being photo-ionized by the FEL pulse. The kinetic energy of the resulting electrons is modified by the electric field of the THz radiation, when it is co-propagating through the target. If the electron wave packet is short compared to the period length of the terahertz field (> 500 fs in our case), the temporal structure of the wave packet will be mapped onto the kinetic energy distribution of the emitted electrons. The pulse duration can be extracted from the broadening of the peaks measured in the photoelectron spectrum due to the presence of the THz field. The shift of the kinetic energy peaks provides the arrival time. The THz streak camera was build and installed at FLASH at the PG0 beamline. This beamline has the capability to use the zero order FEL beam for the streaking set up while the dispersed radiation can be simultaneously used in the PG2 beamline to measure the FEL spectrum with high resolution. The THz radiation is generated by interaction of pulses delivered from the FLASH1 pump-probe laser (800 nm, 80 fs, 6.5 mJ) with a nonlinearly reacting crystal - pulse front tilt optical rectification in a Lithium niobate ($LiNbO_3$) crystal. A THz field strength of ~300kV/cm has been achieved [4].
Several different FEL operation settings have been used to commission the technique in a wide range of single shot pulse durations from around 300 fs to less than 20 fs (FWHM) for a 7 and 20 nm FEL wavelength. As a second important result of the experiments, we could verify the assumption that the electron beam arrival time monitor (BAM) measuring the arrival time of the electron bunches with high precision in the FLASH accelerator is an acceptable measure for the arrival time of the XUV photon pulses in all measured cases. The shot-to-shot arrival time measurement shows a correlation width of 20 fs rms. Thus, the time resolution of user pump-probe experiments (using the pump-probe laser) can be significantly improved by sorting their data with the arrival times measured by the BAM.
[1] W. Ackermann et al, Nature Phot. 1, 336, (2007).
[2] I. Grguras et. al., Nature Phot. 6, 852, (2012).
[3] U. Frühling et. al, Nature Phot. 3, 523, (2009).
[4] R. Ivanov et al., J. Synch. Rad., 25, 26-31 (2018).

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