FEMTOSECOND LEVEL SYNCHRONIZATION OF A LINAC BASED SUPER-RADIANT THz FACILITY

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Abstract

The superconducting radiofrequency (SRF) electron accelerator ELBE at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) is currently upgraded. A SRF Gun and a femtosecond (fs) electron beamline will enable quasi continuous wave (cw) operation with bunch charges of up to 1 nC and bunch durations down to 150 fs (FWHM). The new femtosecond electron beamline will be used to drive one super-radiant THz test facility and one X-ray source based on Thomson scattering. Both of these facilities will at some stage rely on synchronization of external laser systems to the accelerator on the sub 100 fs timescale. In the next few years one focus of the accelerator research activities at HZDR will lie in the development of suitable techniques to timing and synchronizing the accelerator. Our approach is based on an optical synchronization system, adapted from a similar system installed at FLASH [1]. This system is installed and tested in a close cooperation between DESY and HZDR.

CONCEPT

Overview

The femtosecond synchronization system at ELBE is using single-mode optical fibers to distribute stable laser pulses to several remote stations. The laser light is partially used for an optical phase detection scheme to monitor and compensate for jitter and drifts [1]. The master laser oscillator (MLO), operating at 78 MHz, is locked to the master radio frequency (RF) oscillator, which defines the long term stability.

The link stabilizers are adapted from the units installed at FLASH and have been setup at ELBE in collaboration with DESY, Hamburg. In spring 2012 the first prototype link stabilizer has been commissioned at HZDR and showed promising performance [2].

The layout of the synchronization system is shown in Figure 1.

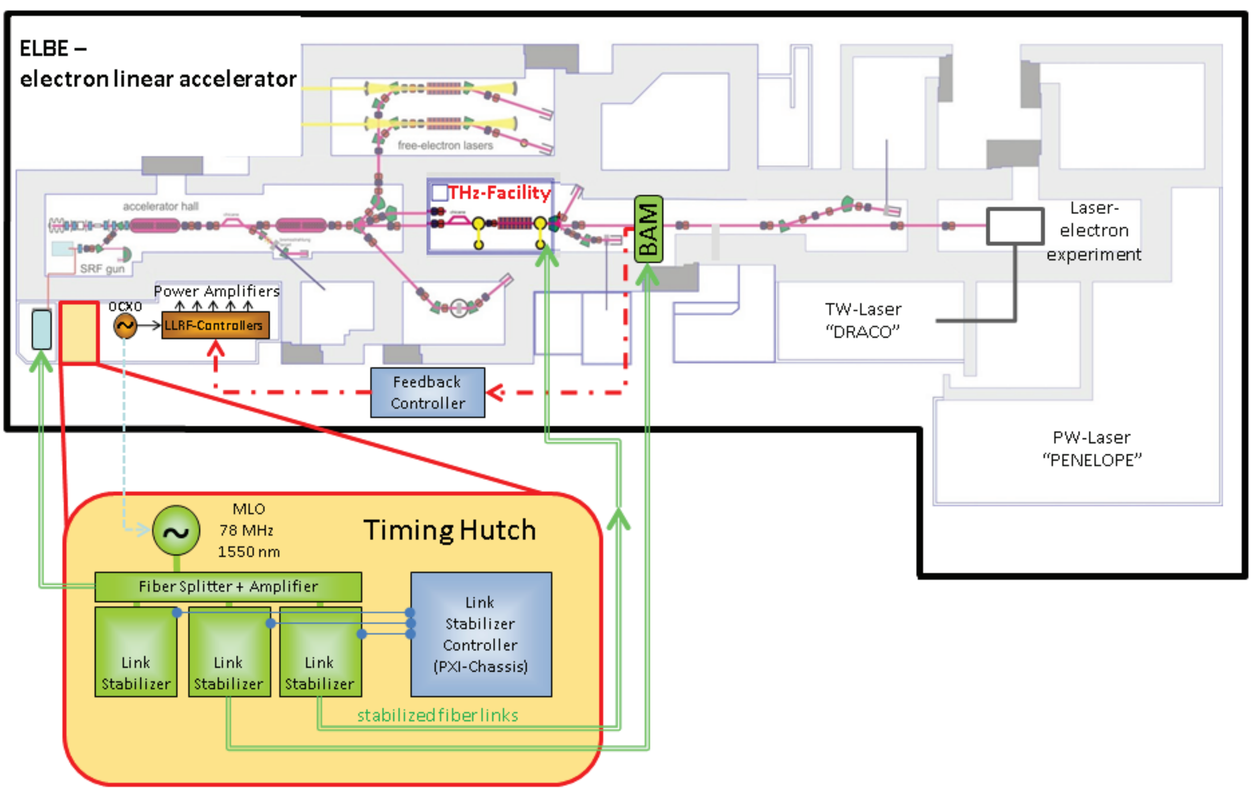

Figure 1: ELBE layout with synchronization system for THz facility.

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ISBN 978-3-95450-123-6

The stabilized laser pulses are used as the timing reference to lock pump-probe lasers to the accelerators RF. The optical pulses are detected using a photo diode, which generates a frequency comb with the fundamental wave and all its harmonics up to the photo diodes bandwidth. The fundamental frequency of 78 MHz is used as a coarse lock to fix the laser pulse to the right RF bucket. Usually one of the upper harmonic is used for a fine lock, i.e. for a more sensitive phase detection and control.

In future an all optical lock can be realized using a two color balanced optical cross-correlator scheme [4].

The availability of stabilized ultra-short laser pulses at any location on the machine allows for the employment of advanced techniques for timing and electron bunch diagnostics like electro optical sampling and bunch arrival-time monitoring. Since the ELBE accelerator runs in a quasi – cw mode of operation specific optimization of such schemes can be envisioned, e.g. by making use of phase sensitive detection [3].

Timing Hutch

The Timing Hutch offers a temperature stabilized und clean environment for the MLO and the link stabilization units. It is located close to the accelerators RF systems and electron sources to minimize the residual jitter caused by grounding and thermal issues.

Linac Based Super-Radiant THz Test Facility

One application of the new fs – electron beamline at ELBE is to generate and study superradiant THz pulses from (i) a coherent transition/coherent diffraction source and (ii) from a dedicated THz undulator device (for details see [5]). In medium and long term, once the process of THz generation is fully understood and reliable operation can be guranteed, the THz pulses shall be utilized for dedicated THz pump laser probe experiments. Pilot facilities at the linac of the FLASH FEL [6],[7] have shown that super-radiant THz facilities of this kind can generate THz pulses with field strength up to GV/m. The interest of the material and life science community in such a facility lies in the possibility to study the influence of such extreme unprecedented fields on matter. While some experiments would study the effects of the high electric fields on the materials "post mortem", most experiments will likely study the dynamic of processes induced by THz pulses. Recent experiments have shown that the macroscopic properties of matter such as conductivity or even superconductivity can be controlled by high THz fields [8],[9] on femto to picoseond timescales. In such experiments it would be highly desirable to study the dynamics on a sub THz cycle timescale in order to understand wether such phenomena are related to the THz field or the THz pulse intensity envelope. Figure 2 shows a narrow bandwidth pulse (3 THz) sampled in a two color pump probe experiments at the pilot facility at FLASH where a novel self-synchonized scheme based on the generation of the probing X-ray pulse and the pumping THz pulse from the same electron bunch provides few femtosecond synchonization [6],[7],[10]. In the optimum case, and as a long term goal, such a sub cycle time resolution should also be achieved at ELBE. Since the THz frequencies range from 3 THz to 0.1 THz this requires a sub 100 fs synchronization of the accelerator and the external laser systems.

Laser Systems

The THz laboratory will be equipped with a commercial Ti/Sa based laser system comprising of a Verdi G pump laser, a Vitara laser oscillator (delivering 20 – 100 fs pulses at a rep rate of 78 MHz and with nJ pulse energies), a RegA 9000 regenerative amplifier (delivering 100 fs pulses at μJ pulse energies) and different optical parametric amplifiers that can provide few 10's of nJ pulses over a wavelength range from the ultraviolet to near infrared. The laser system will at a later stage be complemented by the mJ laser- amplifier system of the Legend family [5].

Laser Lock

The Vitara Laser oscillator is locked to a reference signal using the Synchrolock AP electronics [11]. It offers the opportunity to lock the laser to an RF source and also to a second Ti:Sa Laser system using an optical input. This optical input has to be modified to accept the wavelength range of the MLO.

Locking the laser systems can be done in two ways with different accuracy. The first option is using an electrical reference signal at fundamental frequency to do a coarse lock. The Synchrolock electronics generates an electrical frequency comb with the spacing of the fundamental wave. The 9^{th} harmonic is used for the fine lock.

The second option of locking the laser is using the modified optical input and connecting the stabilized optical pulses directly to the Synchrolock. Since there is no conversion to RF and filtering outside the lock electronics, noise sources are minimized. The optical input is also advantageous to avoid ground loops.

The characterization of the different locking schemes will be done once the laser system is fully in operation.

Electron Bunch Diagnostics

The short and medium term goal of the THz test facility lies in the development of THz based electron bunch diagnostic. One important focus will be to develop concepts for online diagnostic of the arrival time jitter between the THz pulses/electron bunches and the external laser systems but also for an analysis of the electron bunch form. The strategic goal is the development of tools that are especially adapted to the requirements or quasi cw accelerators [1] [12].

ISBN 978-3-95450-123-6

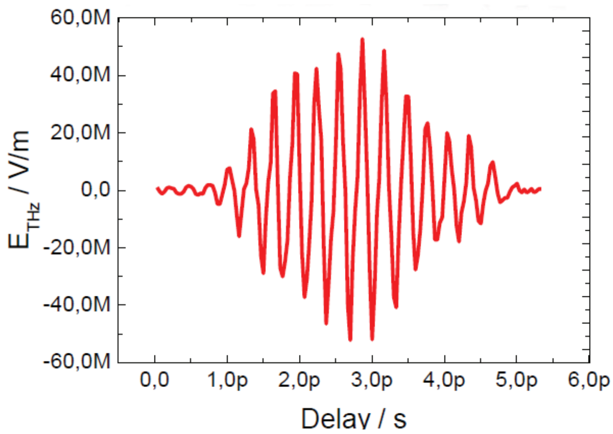

Figure 2: 3 THz pulse of the pilot super-radiant THz facility at FLASH [5] sampled via photoelectron streaking by naturally synchronized fs X-ray pulses[8],[10]. For a sub-cycle sampling at 3 THz a sub 100 fs synchronization is required.

SUMMARY AND OUTLOOK

The synchronization system is currently built up in parallel to the super-radient THz source at ELBE. The desired synchronization of better than 100 fs could be demonstrated frequently at FLASH and also already on a laser table scale prototype setup at ELBE. The next steps will be efforts to install timing distribution systems that allow transferring the timing signals with sub ps stability to different end stations including the THz facility. As soon as THz pulses of sufficient intensity become available performance of the timing and synchronization systems will start. These experiments, together with the signals from the beam arrival monitors and beam compression monitors, shall then in a second step be used for an appropriate feedback on the accelerator phases. The ultimate goal is to reach sub 100 fs synchronization and timing by 2015.

All installations offer the option of pulsed and cw operation. Since ELBE is a continuous wave linac we believe that we can benefit from phase sensitive techniques techniques, which may help us improve the measurement sensitivity considerably [3,12]..

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