STATUS OF THE FEMTOSECOND SYNCHRONIZATION SYSTEM AT ELBE

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Abstract

The superconducting electron accelerator ELBE at Helmholtz-Zentrum Dresden-Rossendorf is currently upgraded to enable continuous wave operation with bunch charges of up to 1 nC and durations down to 200 fs (RMS). The new beamline will drive a THz source and an X-ray source based on Thomson backscattering [1]. Both light sources call for synchronization on the femtosecond scale to enable time resolved experiments.

MOTIVATION

Until August 2012 there will be a new beamline at ELBE which allows compressing high charge electron bunches to a few hundred femtoseconds. These bunches will be used to produce intense radiation in the THz spectra. It is planned to perform pump-probe experiments with femtosecond resolution.

The second challenging experiment is Thomson backscattering in a perpendicular setup where the laser photons are scattered 90° from the relativistic electrons. We demonstrated the working principle in a 180° setup where the timing jitter between both beams is less critical and prepare an experiment with angular collision. Then the timing stability at the interaction point has to be at least as low as the electron bunch length, i.e. below 200 fs.

CONCEPTUAL DESIGN

Overview

In collaboration with DESY, Hamburg a synchronization system based on a mode locked laser as an optical master oscillator will be used to ensure a timing stability on the few 10 fs scale [2]. The laser will be locked to the accelerators radio frequency (RF) master oscillator and the pulses will be distributed via optical fibers to the remote stations. To detect delay changes in the optical fibers caused by temperature drifts and mechanical stress, part of the laser light is reflected at the far end and sent back to the near end of the transmission line. Phase changes are measured using a balanced optical cross correlator which generates an error signal of a few mV per femtosecond. The error signal is fed into a fast digital controller to compensate timing variations in two steps. Fast changes are minimized using a fiber piezo stretcher while slow changes are compensated by an optical delay stage offering a broader tuning range [4].

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Hardware

For the Optical master oscillator a commercial solution was chosen. The Onefive Origami 15 is a robust system showing very low phase noise [3]. It is locked to the accelerators RF using the available phase lock electronics. The measured phase noise of the HZDRs Origami was below 6 fs [1 kHz; 10 MHz].

The link stabilizer contains the optical cross correlator, the coarse phase measurement, the actuators for the phase correction, dispersion compensation and the polarization control, designed by DESY, Hamburg [4].

Since the link mechanics was engineered and improved in several iterations it shows very good performance and long term stability at the Free-Electron Laser in Hamburg (FLASH). Still there is a lot of research and development going on to reach even higher phase stability. In future numerous links of this kind will be installed at the European XFEL currently under construction in Hamburg.

DESY kindly provided these mechanics including the necessary knowledge and support to HZDR to build up a similar system.

To operate the link stabilizer a fast digital controller is necessary. Together with fast ADCs and DACs it reads the balanced detectors output and controls the two actuators to compensate for phase changes. In contrast to DESY at ELBE a NI PXI- based System is used. A typical chassis contains a National Instruments (NI) Realtime Controller, a Board with a FPGA extended with fast analog inputs and outputs. A second board with slow ADCs is used to monitor power values and to do the slow polarization control feedback. The motor controller is connected to the board with an extended bus structure. The FPGA is running independently from the main program to ensure a high loop bandwidth. The communication with the front panel is done via logical channels.

Software

Using National Instruments Hardware makes it beneficial to use NI LabView for the programming of the control loops and the user interface. As mentioned above the programming is split into two parts. The fast controller for the link stabilization is done with the FPGA module for LabView and a slow part for polarization control, data logging and the user interface. This allows starting to program in both tasks without interfering each other. Only the way of exchanging data has to be defined beforehand.

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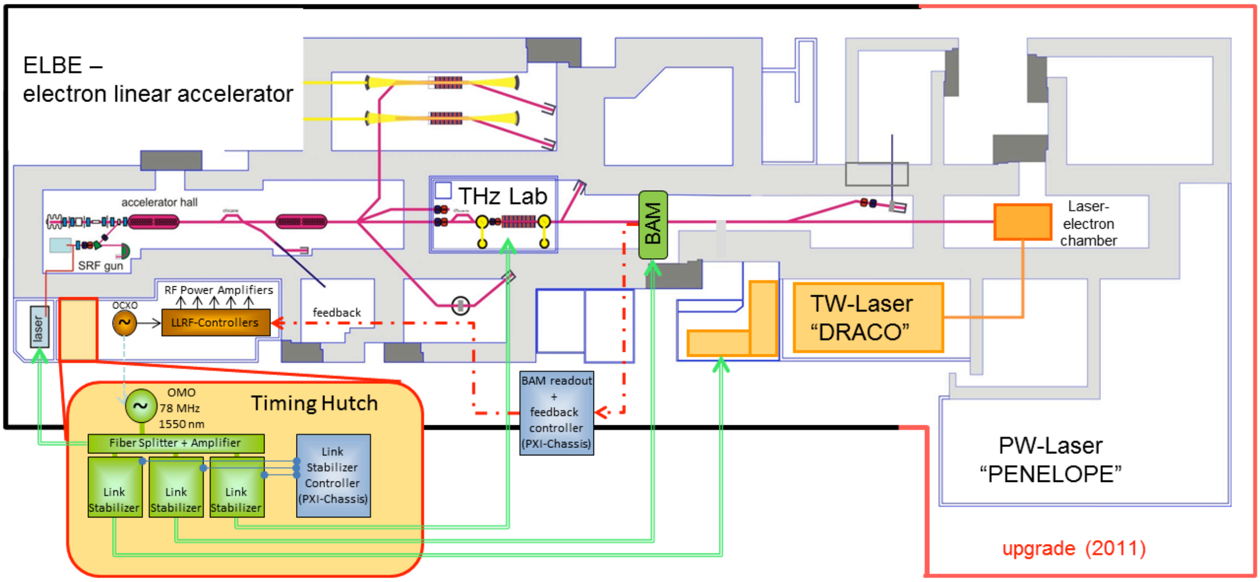

Figure 1: ELBE-Layout with synchronization system.

Diagnostics and Feedback

Beside the synchronization of remote clients the stabilized laser pulses can be used for new methods of electron bunch diagnostics like bunch arrival time monitors (BAM) [5]. BAMs allow to measure arrival time jitter of electron bunches with a resolution of a few femtoseconds without affecting them. This information will be used to enable a feedback on the phase and amplitude values in the low level RF control as shown by DESY in macro pulse regime [6]. Since ELBE is a continuous wave machine the feedback controller is able to minimize phase deviations without being interrupted by macro pulse breaks.

TIMING HUTCH

Since the optical synchronization system is based on the generation and distribution of laser light a clean and laser safe environment is mandatory. Therefore we built a dedicated timing laboratory that contains all critical parts needed for the optical synchronization. The laboratory has been built between the cathode laser for the super conducting RF (SRF) gun and the low level control electronics. That means all parts defining the phase stability of ELBE are close together which minimizes the influence of noise sources.

Most of the available space in the hutch is occupied by an actively stabilized optical table. It supports the laser system as well as the link stabilizers. The control electronics and power supplies will be mounted in dedicated shelves which will be installed in the next weeks. The instruments with the highest power consumption will be installed to a water cooled server rack which will be setup adjacent to the table. The Synchronization Laboratory is air conditioned which keeps the peak-to-peak temperature deviation below 1 K. The optical fibers connecting master laser and link stabilizers will be housed in insulated boxed to minimized temperature drifts.

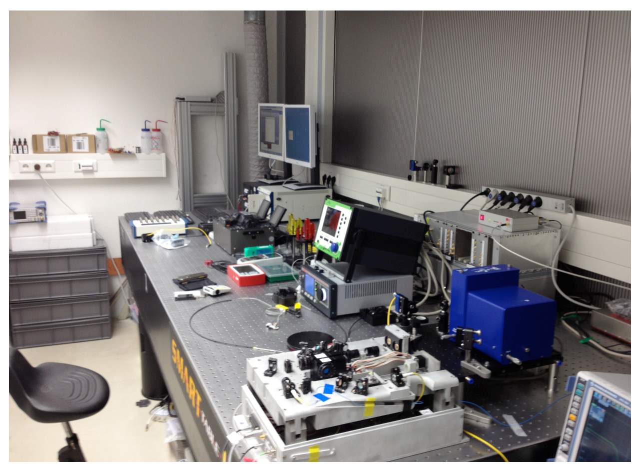

Figure 2: Timing Hutch in commissioning phase. In front prototype of link stabilizer at HZDR.

COMISSIONING

Link Assembly

The link mechanics has been assembled and the optical elements have been aligned. Due to the large spectral bandwidth of the laser pulses of 35 nm the compensation of the chromatic dispersion in the link fiber is very challenging. While the initial laser pulse has duration of 76 fs the reflected pulse has a minimum of 400 fs (FWHM). This is due to the matching of the dispersion behavior of the dispersion compensating fiber (DCF) and the standard singlemode fiber. During the summer there will be tests with different types of DCF. Nevertheless we were able to generate a signal on the balanced detector

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which indicates the phase drift of reflected pulse with respect to the reference pulse.

First Measurements

We were able to generate a cross-correlator signal of maximum 3.3 V peak-to-peak. The balanced detector was set in high sensitivity mode which increased the noise to 5 mV (RMS). **Figure 3** shows the signal of the first prototype link. The gradient of the slope will increase when the reflected pulse duration decreases.

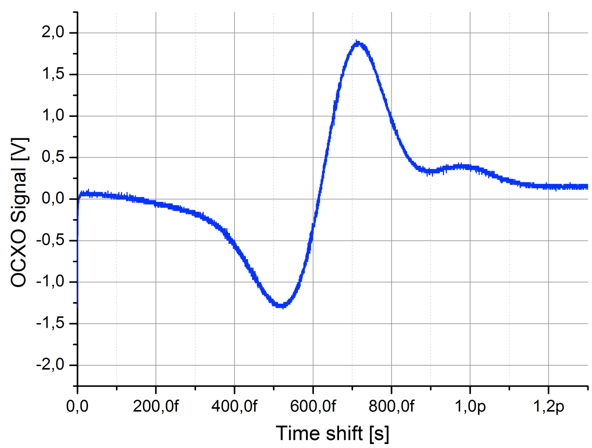

Figure 3: Cross correlator output signal.

A calibration of the slope was done by exciting the piezo stretcher with a ramp generator. With the stretching factor one can calculate the slope gradient of 0.1 fs/mV. This signal was used for a first test of the link stabilization. Since the final software environment is not available at the moment a simple control loop was used as a test bed. We were able to stabilize the link with an in-loop-jitter of less than 20 fs peak-to-peak, for more than one hour. **Figure 4** shows the in-loop-jitter for the first link stabilizer. Due to an error in the motor control the link fell out of lock when the piezo driver had reached its limit. There will be an out-of-loop measurement with a second cross correlator to validate these measurements.

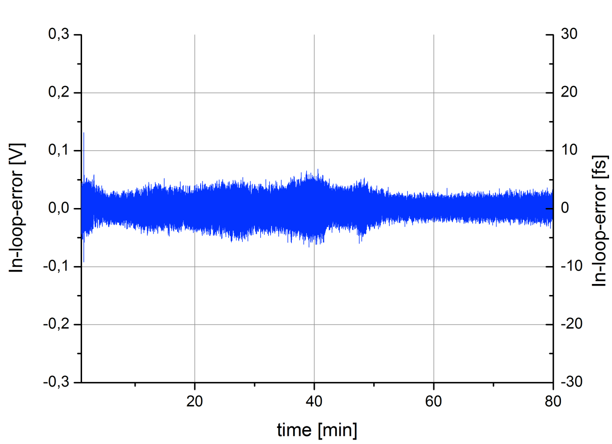

Figure 4: In-loop-error from first link stabilizer at ELBE.

Software Status

Since the first link stabilizer has been assembled and commissioned the software environment has to be set up. The first measurements have been done in a test bed with limited features. In the near future, the missing functionality like polarization control and power monitoring will be implemented. The control for the link stabilization will run independently from the accelerators control system WinCC.

SUMMARY AND OUTLOOK

At the superconducting CW electron accelerator ELBE we started to setup an optical synchronization system with desired stability on the femtosecond scale. Supported by the DESY synchronization team a first link stabilizer has been assembled and commissioned in a dedicated synchronization laboratory. The master laser oscillator showed excellent phase noise performance and output power stability. The balanced optical cross correlator in the link stabilizer showed an error signal of up to 0.1 fs/mV. Further compensation of chromatic dispersion in the fiber link to achieve shorter pulse length will lead to a higher cross correlator signal and improve the signal to noise ratio. Currently the software development is going on to finalize the digital control loops and the graphical user interface. Until the end of 2012 two additional stabilized links will be set up. One will be used to drive a bunch arrivaltime monitor to measure the accelerators stability. In future the generated error signal will be used to for ab arrival time feedback on the LLRF controllers.

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