

OPTICAL SYNCHRONIZATION AND ELECTRON BUNCH DIAGNOSTIC AT ELBE

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Abstract

The commissioning of the extended linear electron accelerator ELBE at Helmholtz-Zentrum Dresden-Rossendorf started in autumn 2012. The new beamlines will deliver short electron pulses with 150 fs duration and bunch charge up to 1 nC. This will drive two THz-sources, one broadband CTR/CDR and a narrowband undulator source.

To enable highly resolved pump-probe experiments with table top laser sources pump and probe beams have to be synchronized on a 100 fs time scale.

This paper describes how the synchronization at ELBE is done for the upcoming experiments and focus on first measurement results of the ELBE bunch arrival time monitor (BAM) based on that system.

REQUIREMENTS

The THz facility TELBE requires femtosecond resolution to perform: (i) THz-pump laser-probe experiments with subcycle resolution and (ii) to perform sequential time domain spectroscopy. For (i) one requires that the synchronization is at least by a factor of 4 better than the cycle time of the highest THz frequency available from TELBE (3 THz) which is ~ 300 fs. So that the optimal synchronization would require to be in the sub 100 fs regime.

The second challenging experiment is Thomson backscattering in an angular setup where the laser photons are scattered from the relativistic electrons. First experiments have been carried out in a 180 deg setup where the timing jitter between both beams is less critical [1]. Using an angular collision, the timing stability at the interaction point has to be at least as low as the electron bunch length, i.e. below 150 fs.

SYNCHRONIZATION

A prototype link of the femtosecond synchronization system at ELBE has been set up in 2012 and met the specifications needed [2]. The system is based on a low noise laser oscillator which is locked to the accelerators RF reference. The laser signal is split in several branches and transmitted to the remote stations via stabilized fiber links. The system is derived from the one used at FLASH and has been set up in collaboration with DESY, Hamburg [3].

ARRIVAL TIME MEASUREMENT

Working Principle

The laser pulses, provided by the synchronization system, are used as a timing reference for the arrival time measurement. For this, a pickup signal generated by the electric field of the passing electron bunches is overlapped in time with one of the laser pulses inside an electro-optic intensity modulator (EOM). Depending on their temporal relation, the laser pulses are modulated in amplitude. That means the arrival time information is coded into the amplitude variation of one laser pulse. Laser pulses that do not overlap with one of the pickup signals are used as an amplitude reference. The intensity relation between modulated and reference pulses can be measured and calibrated for different time delays. This calibration plot is used for calculating the relative delay during the measurement. The electro-optic technique allows single bunch arrival-time measurements for pulsed and CW machines [4][5].

Setup

The stabilized laser pulses are transmitted to the BAM electronics via singlemode optical fibers. Since the slope (i.e. the signal bandwidth) of the bunch signal is directly contributing to the measurement resolution, one has to avoid long cabling between EOM and beamline pickup. Therefore the BAM-frontend has been installed underneath the beamline what leads to a cable length of 2 meters. To protect the electronics from radiation it was covered with 0.1 m of lead in any dimension.

The BAM-frontend houses two electro-optic modulators, one for the fine and one for the coarse channel. To adjust the timing overlap between laser and pickup signal an optical delay line (ODL) is installed. A second one is used to compensate for differences in cable and fiber length in both channels. To recover the phase information of the laser signal a coupler is used to tap of a small fraction of the intensity signal. This signal is sent to the readout electronics and used to clock the ADC.

All optical fibers and the EOMs are mounted on an actively temperature stabilized plate to avoid long term drifts. **Figure 1** shows a schematic of the BAM frontend.

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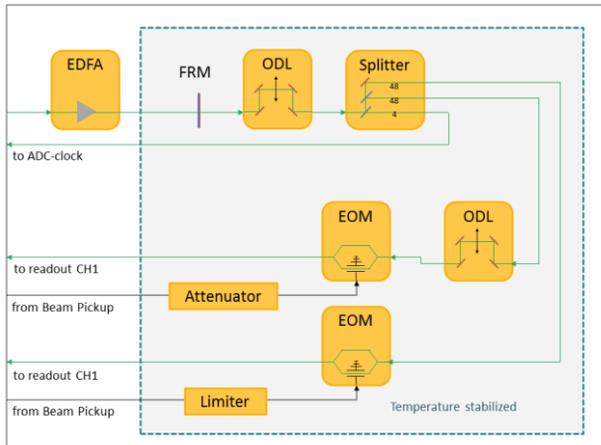


Figure 1: BAM-frontend schematic

Readout

The modulated laser pulse trains and the clock signal are transmitted to the readout electronics using non stabilized fibers. Photodiodes convert the optical signals into electrical and feed a fast ADC. The ADC is set up to take one sample on top of each laser pulse (78 MHz). A Trigger coming from the accelerator marks the modulated sample and starts the data acquisition. Fast data processing is done by a FPGA that calculates the baseline value and the modulation for every bunch.

In addition to the time domain readout one can benefit from the CW bunch train of the ELBE accelerator by measuring in frequency domain. During the commissioning we were using a RF spectrum analyzer measuring on the first modulation harmonic. For a standard measurement one can use a lock-in amplifier, locking at the modulation signal. In this case the single bunch information is lost but the signal-to-noise ratio increases by neglecting ADC-jitter and narrowing the spectra. This technique can be used for a slow feedback on the accelerator to stabilize the arrival time.

First Results

After tuning the beam in the new accelerator section, the laser reference signal was delayed using an IQ-phase shifter to find the time overlap between wakefield and laser signal.

At first, the modulation signal has been measured in time domain. **Figure 2** shows the amplitude of the modulated laser pulses for 77 pC and 20 pC during a continuous phase shift of 550 ps. Two things can be seen easily. First, the signal does not show a single cycle slope as expected. The latter cycles are caused by ringing of the pickup signal and by wakefields excited inside the beamline by the bunch itself. Since the measurement is done at a fixed working point on the steepest slope at the beginning the ringing is negligible for the readout. Secondly the modulation amplitude is changing with the bunch charge. This is caused by the amplitude dependence of the pickup signal to the bunch charge. To

avoid influences on the measurement a calibration of the system has to be done with respect to the bunch charge. To overcome this effect we have installed integrated current transformers (ICTs) close to the BAM stations. ICTs are able to measure the charge of single electron bunches. That information will be used to correct the BAM readout.

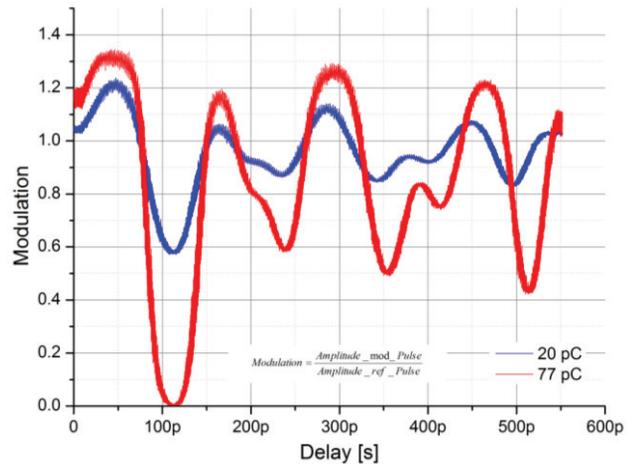


Figure 2: Laser modulation w.r.t. time delay

Since ELBE is a CW accelerator the modulation readout can also be done in frequency domain. Therefore we were operating the machine at 100 kHz repetition rate and measured the photo diode signal with a RF spectrum analyzer. Both carrier and pickup signal are pulsed signals which lead to a broad spectrum containing the fundamental and all harmonics up to the frequency cutoff. The EOM combines both signals as shown in **Figure 3**. The spectrum was taken at the monitor output of the readout electronics explaining the rather small signal levels.

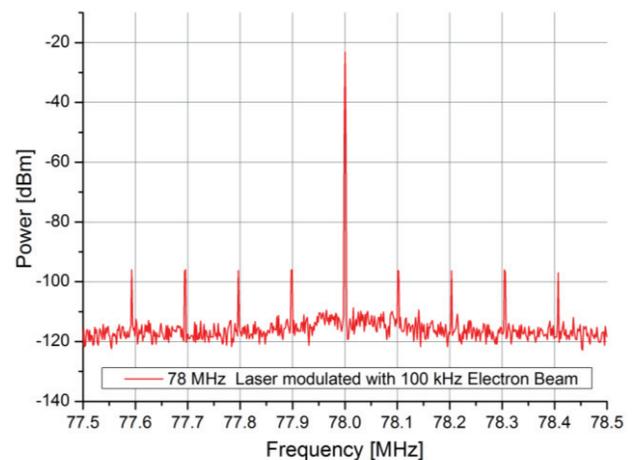


Figure 3: Spectral measurement of 78 MHz (laser) carrier modulated with 100 kHz (electron) pulses

To qualify the influence of the time delay to the amplitude, the spectrum analyzer was operated in zero-span mode. That means the frequency was set to 78.1 MHz, which is the first modulation product, and the frequency sweep was set to zero. Subsequently one could observe the amplitude modulation over time. **Figure 4** shows the result of this measurement at a bunch charge of 77 pC. The highest signal modulation leads to a dynamic range of about 35 dB.

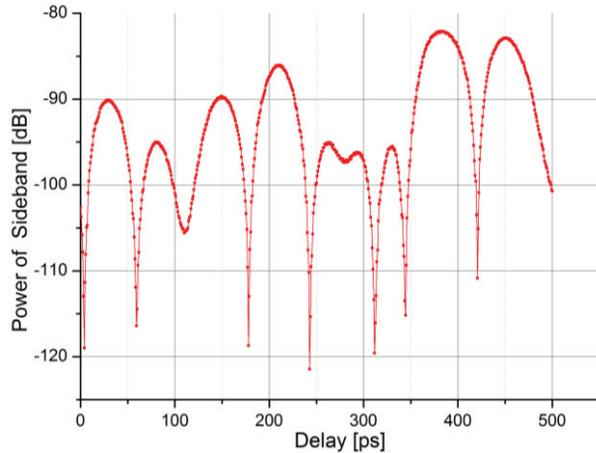


Figure 4: 78.1 MHz- signal w.r.t. time delay

The readout in frequency domain has lower requirements on the readout electronics and is more robust because the ADC does not have to be phase locked to the laser pulses. However the arrival time information of single bunches cannot be extracted anymore. So this method can be used for slow feedback control loops. If information about shot to shot jitter is required the time domain measurement is done in parallel.

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 parallel one prototype of a bunch arrival time monitor has been set up and tested. The setup was working as expected. Beside the common time domain readout a spectral data evaluation has been done. This method showed a dynamic range of ~35 dB.

The functionality of the BAM has been tested for a couple of hours. Using the BAM at ELBE as an online diagnostic tool a lot of measurements will have to be done. The characterization includes variation of bunch charge, bunch form, bunch length, electron energy and repetition rate. Currently the readout and the electronics are reworked to ensure on demand measurements with long term stability.

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