ELECTRON BUNCH DIAGNOSTIC AT THE UPGRADED ELBE ACCELERATOR: STATUS AND CHALLENGES

M. Kuntzsch#, HZDR, Dresden Germany, TU Dresden, Dresden, Germany
Stefan Findeisen, Michael Gensch, Bert Windisch Green, Jens Hauser, Sergey Kovalev, Ulf Lehnert, Peter Michel, Fabian Roeser, Christof Schneider, Rico Schurig , HZDR, Dresden, Germany
Alaa Al-Shemmary, Michael Bousonville, Marie Kristin Czwalinna, Torsten Golz, Holger Schlarb, Bernhard Schmidt, Sebastian Schulz, Nikola Stojanovic, Silke Vilcins, DESY, Hamburg, Germany
Eugen Hass, Uni HH, Hamburg, Germany

Abstract

Within the ELBE upgrade towards a Center for High Power Radiation Sources (HSQ), a mono energetic positron, a liquid lead photo neutron source and two new THz sources have been installed at the superconducting electron linac at ELBE. A variety of established as well as newly developed electron beam diagnostics were installed and tested. This paper presents first results which have been achieved with the currently existing prototype bunch arrival time and bunch compression monitors (BAM, BCM) as well as one versatile electro-optical sampling (EOS) set-up.

ELBE UPGRADE

The superconducting continuous wave electron accelerator ELBE in operation since a decade has been upgraded to offer capabilities for new experiments. After the accelerating structures a new beamline branch has been installed which transports bunches to four new secondary sources: Firstly, a facility for super-radiant THz pulses [1], secondly a positron source which emits positrons by pair production and thirdly, a photo-neutron source which offers the capability of neutron time of flight measurements. By the end of 2013 the beamline will be finalized by connecting it to the high power laser chamber to enable an X-ray source based on inverse Compton backscattering.

For the THz generation and a high X-ray photon yield a high charge density and short electron bunch duration is needed. Therefore, a second bunch compressor chicane is added to the beamline which enables a compression down to 200 fs and a new SRF Gun is currently constructed that shall allow to increase the charge up to 1 nC.

All new sources rely on stable beam conditions like charge, bunch length as well as bunch arrival time. To address these needs diagnostics for all relevant parameters is necessary.

Since the bunch compression scheme using two chicanes leads to a high sensitivity on instabilities of the accelerating RF field and electron source jitter the diagnostics shall eventually be used to feedback on the accelerating structures in a future step.

m.kuntzsch@hzdr.de

BUNCH COMPRESSION MEASUREMENT

Setup

The bunch compression measurement is based on the evaluation of CDR/CTR radiation emitted by a screen which is passed by an electron bunch. The setup at ELBE is adapted from the FLASH design at DESY which is described elsewhere [1][2]. To cover a broad spectral range two detector types are used, one broad band pyroelectric and one Schottky diode detector sensitive between 110 – 170 GHz. The THz beam is focused using two parabolic mirrors and is split by a wire grid polarizer so both detectors are measuring in parallel. While the Schottky diode detector has a fixed position the pyroelectric detector can be moved forward and backward to optimize the focus. Figure 1 illustrates the setup used at ELBE (more details can be found in [3]).

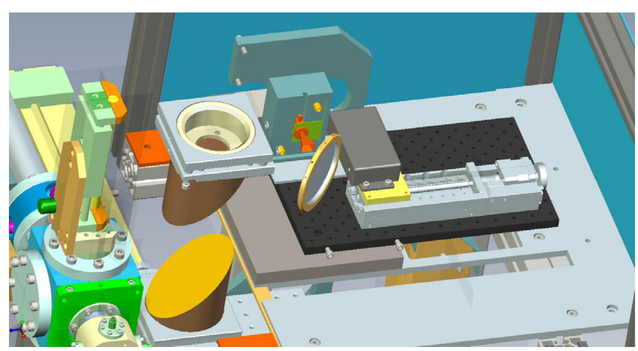

Figure 1: Technical drawing of ELBE BCM Setup with RF detector (orange) and pyroelectric detector (grey).

First Results

The first measurements have been performed using only the CTR screen since the CDR screen will be mounted only in the upcoming shutdown. Both detectors show a clear signal depending on the bunch charge and compression factor. Figure 2 shows the time domain response of both detectors on a bunch of ~3 ps duration and 90 pC charge. The Schottky detector shows some ringing after the main pulse which is caused by an impedance mismatch.

ISBN 978-3-95450-127-4

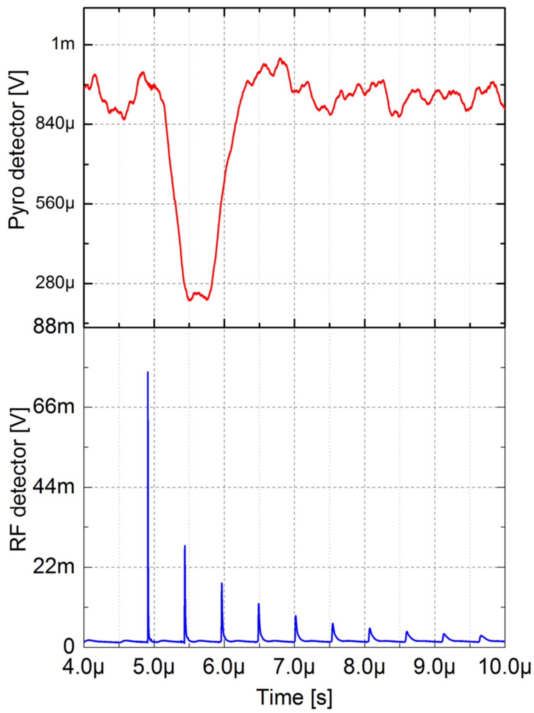

Figure 2: Output signals of the pyroelectric detector (red) and the RF detector (blue) at 90 pC and low compression (~3 ps bunch length).

While the pyroelectric detector has a low response at longer bunches the Schottky diode gives already a good signal. More importantly the Shottky diodes are fast enough to resolve individual bunches up to repetition rates of 13 MHz (which is the full repetition rate of the ELBE accelerator). Once the bunches are compressed the pyroelectric signal grows rapidly what makes it predestined for measuring short bunches in the sub ps regime.

Further shifts will be spent on characterizing both detector responses for different settings at ELBE.

ARRIVAL TIME MEASUREMENT

Setup

The bunch arrival time measurement benefits from a laser based synchronization system which is currently set up at ELBE that offers stable laser pulses as a timing reference. The first prototype showed a stability of <50 fs over several hours [4].

The stabilized pulse train is sent to an electro-optical modulator (EOM) which is connected to a broadband button-pickup installed in the beamline. When both signals overlap in time the laser pulse gets modulated in amplitude. That means the arrival time information is mapped into an amplitude variation. After a calibration run this setup is able to provide a resolution on the femtosecond scale.

One coarse arm which uses an attenuated pickup signal ensures keeping the right working point while the fine channel gives a high resolution but suffers from ambiguity at higher bunch charge.

To avoid timing drifts the optical frontend has been installed close to the beamline and is actively temperature stabilized. The setup is shown in Figure 3.

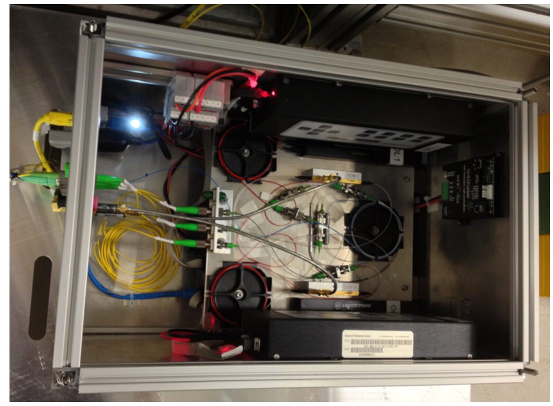

Figure 3: BAM- frontend which is installed next to the beamline.

The arrival time measurement as well as the bunch compression monitor is sensitive to charge variations. The measurements are only valid for a given data set. That means one has to calibrate for several setpoints and make sure to keep that consistent. Integrated current transformers (ICTs) are installed and used to measure the bunch charge. In future this information will be directly encountered by the BAM and BCM readout.

First Results

Currently ELBE can generate bunches up to 100 pC charge. So all measurements are performed up to that limit. For the first test the phase of the master laser oscillator (MLO) was shifted with respect to the accelerators RF. In parallel the modulation factor has been monitored to evaluate the BAMs response. This measurement was done for several bunch charges. Above 90 pC overmodulations starts which means the current setup is able to use the full range of the fine channel.

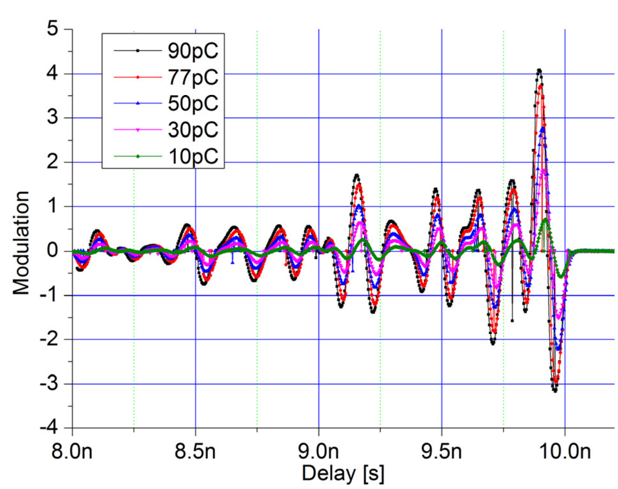

Figure 4: Modulation factor of laser signal while scanning the laser phase with respect to the master oscillator.

ISBN 978-3-95450-127-4

The sensitivity increases when the EOM is driven with a higher voltage. Right now the measurement accuracy is ~300 fs at maximum charge. To overcome this drawback a newly designed pickup will be installed during the next shutdown period which offers a broader spectral response [5]. In combination with a broadband EOM the setup can deliver a better resolution at low bunch charge.

The superconducting photo injector is designed to deliver bunches up to 1 nC charge, which would already enable measurements with higher precision using the current setup.

ELECTRO-OPTICAL SAMPLING

Setup

An electro-optic sampling set-up has been installed at the ELBE accelerator that measures the electron bunch form and arrival time of the electron bunches via sampling their coulomb field [6].

Since recently also the newly installed THz sources at ELBE (TELBE) can be used for novel approaches of THz based electron bunch diagnostics [1]. Some of the techniques are based on electro-optical sampling (EOS) where a probe laser pulse (TiSa, 800 nm) gets modulated by the super-radiant THz-pulse, generated at the TELBE THz sources, in a ZnTe crystal. This setup also allows measurements of bunch form and arrival time but due to the lab environment the hope is to be able to reach the few –fs regime.

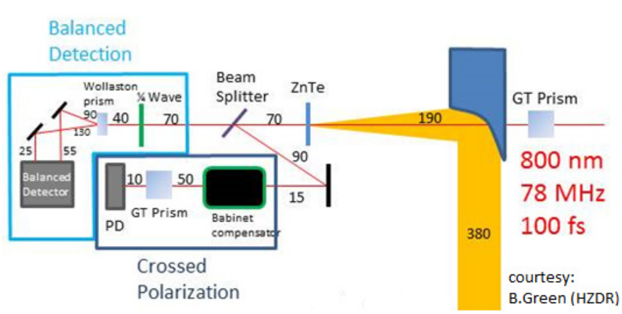

Figure 5: Schematic of the two new THz-EOS setups used at the TELBE laboratory. Two detection principles can be used in parallel. The first is balanced detection which is sensitive to the direction of the electric field and the second is a crossed polarizer detection scheme.

First Results

The preliminary results [1] which have been carried out show a stability of the ELBE accelerator of several ps with respect to the pump probe laser locked to the RF master oscillator. The reason for this relatively moderate synchronization is currently subject of further investigations. Possible sources are drifts of the electron injector, instabilities of the accelerating field inside the cavities or an unstable synchronization of the probe laser system.

Nevertheless we are now able to do a characterization of the ELBE bunches with the help of secondary THz radiation.

SUMMARY AND OUTLOOK

We have demonstrated the successful operation of prototypes for bunch length and bunch arrival time measurement at ELBE as well as a novel EOS setup. These tools are mandatory to identify sources of noise and jitter. Beside extensive accelerator studies all diagnostics will be improved to reach a higher resolution. For the BCM there will be a setup with improved optics and radiation protection. One BAM will be equipped with a newly designed pickup which covers a broader spectral range.

In the long term a beam based feedback using all available diagnostics will be implemented to improve the accelerators stability.

REFERENCES

[1] M. Gensch, et al., in preparation

[2] C. Behrens, S.Wesch, et al., „Upgrade and Evaluation of the Bunch Compression Monitor at the Free- electron Laser in Hambung (FLASH)", Proceedings of IPAC10, Kyoto, Japan, MOPD090

[3] B. Green, et al., in preparation

[4] M. Kuntzsch, et al., "Status of the Femtosecond Synchronization System at ELBE", BIW2012, Newport News, USA, MOBP03

[5] A. Angelovski, et al., "High bandwidth pickup design for bunch arrival-time monitors for free-electron laser", Phys. Rev. ST Accel. Beams 15, 112803 (2012)

[6] C. Kaya, et al. "Phase sensitive monitoring of electron bunch form and arrival time insuperconducting linear accelerators", Appl. Phys. Lett. 100, 141103 (2012)

ISBN 978-3-95450-127-4