ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-TUP007

EXPERIENCE WITH THE SUPERRADIANT THz USER FACILITY DRIVEN BY A QUASI-CW SRF ACCELERATOR AT ELBE

M. Bawatna†, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany
B. Green, Magnet Science & Technology, Tallahassee, FL, USA

Abstract

Instabilities in beam and bunch parameters, such as bunch charge, beam energy or changes in the phase or amplitude of the accelerating field in the RF cavities can be the source of noise in the various secondary sources driven by the electron beam. Bunch charge fluctuations lead to intensity instabilities in the superradiant THz sources. The primary electron beam driving the light sources has a maximum energy of 40 MeV and a maximum current of 1.6 mA. Depending on the mode of operation required, there are two available injectors in use at ELBE. The first is the thermionic injector, which is used for regular operating modes and supports repetition rates up to 13 MHz and bunch charges up to 100 pC. The second is the SRF photocathode injector, which is used for experiments that may require lower emittance or higher bunch charges of up to 1 nC. It has a maximum repetition rate of 13 MHz, which can be adjusted to lower rates if desired, also including different macro pulse modes of operation. In this contribution, we will present our work in the pulse-resolved intensity measurement that allows for correction of intensity instabilities.

INTRODUCTION

The Electron Linac for beams with high Brilliance and low Emittance (ELBE) superconducting radiofrequency (SRF) accelerator [1] is a facility at the Helmholtz Zentrum Dresden Rossendorf (HZDR). At the ELBE user facility, there are two available electron injectors in use [1,2] as in Fig. 1. The thermionic injector, which supports repetition rates up to 13 MHz and bunch charges up to 100 pC, and the Super Radio Frequency (SRF) photo-cathode injector, which is used for experiments that may require lower emittance or higher bunch charges of up to 1 nC. Moreover, the SRF injector at ELBE also has a maximum repetition rate of 13 MHz with different macro pulse modes of operation. The required properties of the electron bunches (form, charge, position) afford electron beam diagnostics that exceeds presently available solutions at ELBE. Here we discuss ideas of suitable electron bunch diagnostic techniques amongst which novel single-shot electro-optic techniques for online monitoring of electron bunch form and arrival time in a new THz lab, equipped with state of the art spectrometers and laser systems.

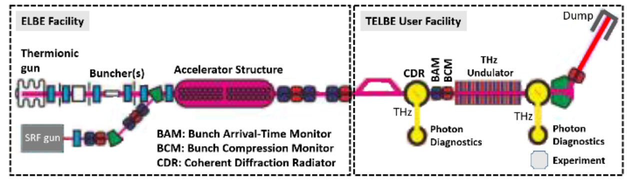

Figure 1: ELBE accelerator beamlines for THz radiation production.

The superradiant THz sources at ELBE accelerator (TELBE) THz facility is performing ultra-fast pump-probe experiments by providing a unique combination of high pulse energies and high repetition rates. In this type of experiment, the electric or magnetic field in the THz pump pulse acts as the excitation of dynamics in the matter. This dynamic in turn is then probed by ultra-short (light) pulses, typically with the sub THz cycle resolution as in [3].

In this paper, we will present the pulse-resolved intensity monitor at TELBE.

The paper is organized as follows: the first section introduces the requirements for the pulse-resolved intensity monitor at TELBE. The second section presents the methods and material used, as well as the intensity instability measurements. After summarizing the results, foreseeable future development and upgrades are discussed.

TERAHERTZ RADIATION DETECTION AT TELBE

Detecting THz radiation can sometimes be problematic because it occupies a position in the electromagnetic spectrum between optical and microwave wavelengths.

There are many different approaches to detecting THz, utilizing a variety of physical phenomena. The ability to detect THz is critical to our work at TELBE user facility, as this is a necessary prerequisite to using it in meaningful experiments and diagnostic setups.

It is crucial to be able to see the intensity of single pulses, to get a reliable measurement of the average power, and to analyze the beam profile. Some experiments require information on the longitudinal (in the time domain) shape of individual pulses or even their actual waveform. The following sections present the pyroelectric THz detection scheme utilized at TELBE to characterize the TELBE THz radiation.

Pyroelectric Detectors

The pyroelectric effect is a phenomenon that occurs when so-called pyroelectric materials change temperature. Changes in temperature cause a change of the electrical polarization, which induces a voltage across the material.

† m.bawatna@hzdr.de

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This voltage then gradually decreases due to leakage current, either through the material itself or through an outside path. Pyroelectric materials can, therefore, be used to detect radiation from the THz to x-ray range by measuring the voltage across them. Any change in voltage is caused by heat being deposited in the material by a light pulse. Thus, the appearance of a detected light pulse is two spikes in voltage, of opposite polarity. The first spike appears when the material is warmed by the light pulse, the second spike is caused when the material cools back to its original temperature after the pulse has passed, while a continuous radiation beam would not lead to a detectable signal.

Front end electronics have been developed at DESY that take these two pulses and output them as a single pulse to make analyzing the detected pulses easier [4]. Fig. 2 shows the signal measured by the pyroelectric detector at TELBE user facility. Pyrodetectors work at room temperature and can be operated at repetition rates in the 100 kHz regime. This type of detector has been most frequently used at TELBE to date because it allows the pulse to pulse intensity detection at the typical operating repetition rate of 100 kHz. It is also easy to convert the signal to a quantitative measure of the pulse energy because the intensity response is linear. There are a few significant problems, though, with this type of detector.

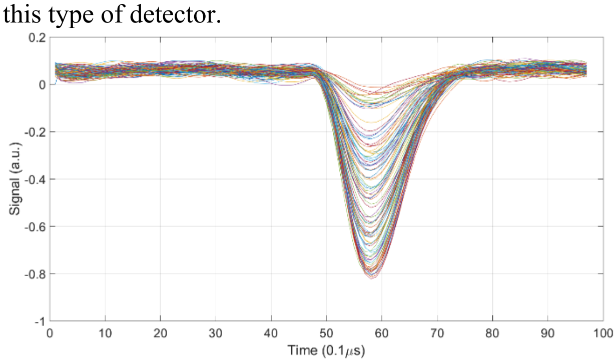

Figure 2: Signal measured by the pyroelectric detector that shows the intensity fluctuation for 10000 THz pulses.

The frequencies of interest in THz are generally difficult to absorb with the standard materials used in pyroelectric detectors. These materials can be transparent to some frequencies in the THz range, which of course make it difficult to detect them. Any frequencies that pass through the absorber material are not measured in the detector, leading to lower readings than the actual beam power. There is also a problem with linearity at high intensities. The unique fast detectors that were developed at DESY have a linear response up to a signal value of 1 V, so it is essential to limit incoming intensity so that the signal is less than 1 V in order to stay in the linear regime. Besides the base noise level is high (µ50 mV). This leads to a large error bar in the few 10% ranges in single pulse intensity measurements. Finally, pyroelectric detectors are too slow to resolve the actual pulse duration.

PULSE-RESOLVED INTENSITY MONITOR AT TELBE

One of the challenges at TELBE is to account for changes in the intensity of the THz pulses. Intensity measurements can be performed alongside the experiment, as shown in Fig. 3. A wire grid polarizer is used as a beam splitter, and a small portion of the THz beam acting as a pump excitation is diverted into a purpose-built pyroelectric detector as in [5]. The most important factors for choosing the specific pyroelectric detector, developed at DESY for the TELBE intensity monitor, are its sufficiently high speed and robustness in. These pyroelectric detectors have a relatively high noise floor of 50 mV. One must also be careful not to put too much intensity onto the detector. If the intensity is too high, the detector no longer has a linear response.

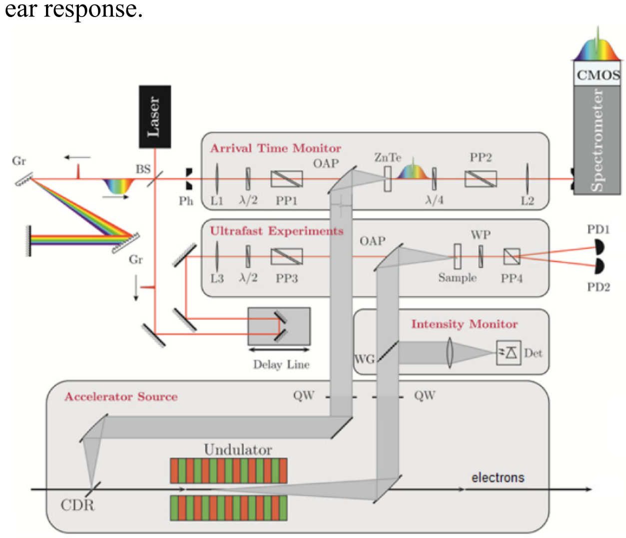

Figure 3: Schematic diagram of the developed pulse-resolved diagnostic at the TELBE facility, combining a 30 fs (FWHM) resolution arrival-time monitor with a pulse intensity monitor.

In this specific case, the linear regime is when the output signal remains below 1 volt. Combined with the noise floor of 50 mV, this results in a relatively poor S/N ratio. The intensity fluctuations and the spectral content for 10000 THz pulses are shown in Fig. 4 and Fig. 5 respectively, taken over 1 second. Major frequencies are marked. A detailed discussion of the observed intensity instabilities will be presented in a full article. Such an analysis can help in identifying the origin of different instabilities.

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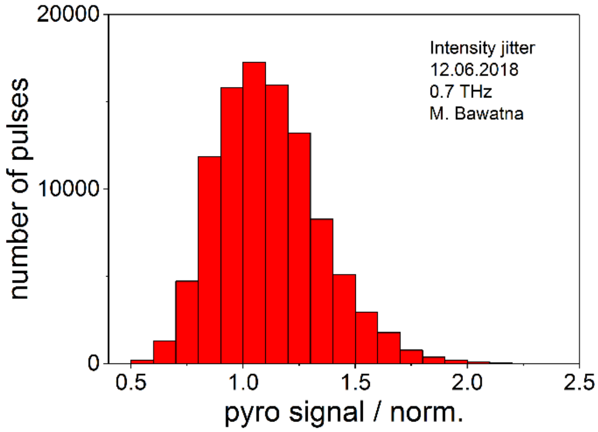

Figure 4: Histogram of the change in the intensity of pulses from the TELBE undulator.

These instabilities can come from any number of sources, from fluctuations in the bunch charge to beam position instabilities to electronic noise in the detection setup.

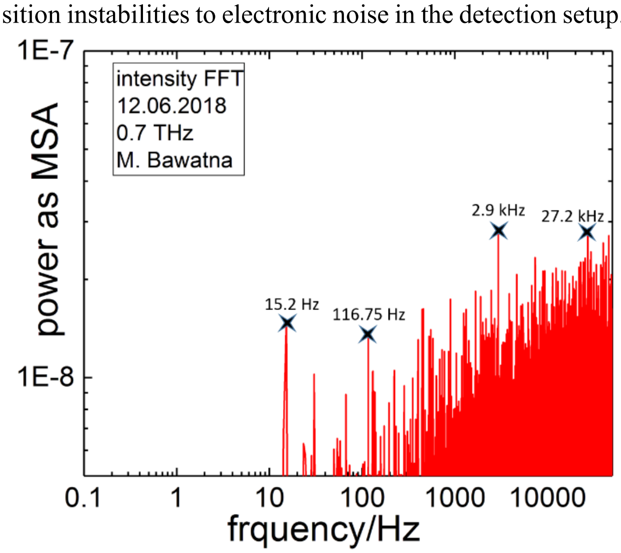

Figure 5: Spectrum of the fluctuations in the beam intensity of the undulator pulses tuned at a 700 GHz, taken over 1 second.

The evaluation of including the pulse-resolved intensity measurement to the data analysis was done on the Electro-optic sampling setup as shown in Fig. 3, which is most commonly used to measure the time-domain form of THz pulses. This effect is quasi-simultaneous and can be used to detect signals on femtosecond timescales.

Data was taken after tuning the undulator at 700 GHz, with a repetition rate of 100 kHz, the beam energy was 24 MeV and a bunch charge was 70 pC. Fig. 6 shows the effect of intensity fluctuation on the Fourier transform of the signal measured by the electro-optic sampling setup shown in Fig. 3.

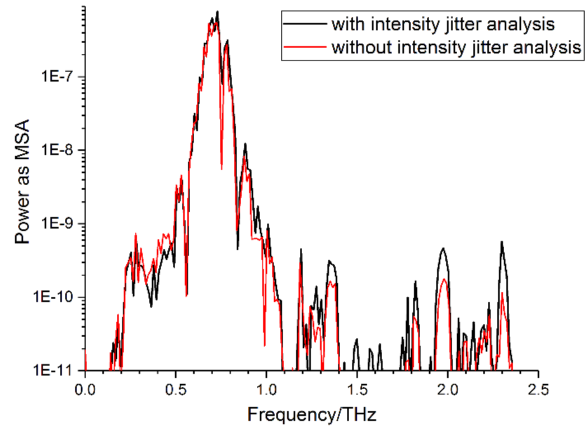

Figure 6: Fourier transform of the signal measured by electro-optic sampling at 700 GHz tune with including the pulse-resolved intensity measurement into the data analysis.

CONCLUSION AND FUTURE WORK

In this paper, the determination of the pulse-resolved intensity fluctuations serves to correct for them in experimental data. Moreover, these instabilities in pulse energy can be harnessed to provide a pulse-energy-resolved measurement utilizing the intensity fluctuations as a fast modulation of the pulse intensity. The pulse-resolved intensity measurement is still under development and evaluation. The results will be presented in a full article.

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