CW BEAM STABILITY ANALYSIS IN TIME AND FREQUENCY DOMAIN

M. Kuntzsch#, HZDR, Dresden Germany, TU-Dresden, Dresden, Germany
U.Lehnert, R.Schurig, J. Teichert, M.Gensch, S. Kovalev, B. Green, P. Michel, HZDR, Dresden, Germany

Abstract

The continuous wave (CW) mode of operation enables a high bandwidth jitter analysis for different diagnostic devices. The measurement is only limited by the bunch repetition rate and the acquisition time, since the bunch train is not interrupted by a macro pulse. At ELBE various diagnostics capable for continuous data acquisition has been installed and used for an analysis of noise sources. This paper comprises measurements from a bunch arrival time monitor (BAM), results from a fast beam position monitor (BPM) installed in a dispersive section and the power spectra from a coherent transition radiation (CTR) source.

INTRODUCTION

General

The recent update of the ELBE accelerator included the installation of a new beamline section which will be used to compress the electron bunches to a duration of 100 fs at a charge of 1 nC. Two THz sources based on coherent transition or diffraction radiation und and an undulator source making use of the compressed bunches [1]. The bunch shaping is done in multiple stages by using two magnetic chicanes [2]. Along the new beamline path a couple of diagnostic stations have been set up to measure the beam properties. Figure 1 gives an overview on the ELBE accelerator and the recently installed femtosecond-beamline. The schematic shows the location of beam diagnostics used to generate the data presented in this letter.

Diagnostics

The bunch compression monitors (BCM) are measuring the power of diffraction radiation generated by the electron bunches travelling thru a hole in a silicon screen. The amplitude increases when the bunch length is reduced. Fast detectors are used to acquire qualitative bunch by bunch information [3][4].

Bunch arrival time monitors (BAM) are used to measure the timing jitter of the electron bunches with respect to an optical reference. The reference is provided by a low noise laser synchronization system. The laser pulse train is modulated by an electro-optical modulator driven by a high bandwidth beamline pickup. The arrival time information is coded into an amplitude modulation of the laser pulses and analyzed with single bunch resolution [5][6]. BAM and BCM are located between the broadband THz source and the undulator. In this section the bunch compression is optimized for the THz production and the diagnostics experiences the same jitter as the secondary sources.

In order to observe beam energy fluctuations a spectrum analyzer was used to measure the modulation of a fast analog BPM readout based on a logarithmic amplifier [7]. The BPM pickup was installed in the dispersive section right after the THz sources before entering the beam dump. Energy fluctuations are translated into position variations after the dipole magnet. By keeping the trajectory of the beam entering the dipole constant measurement artifacts caused by beam pointing could be minimized.

To measure the impact of beam instabilities on the secondary radiation, the power spectrum of the coherent diffraction radiation has been measured inside the THz laboratory. The measurement has been done with a high dynamic range spectrum analyzer connected to a fast pyro-electric detector radiated by the THz field.

All measurements are limited by the bunch repetition rate and the acquisition time. Noise components faster than half the bunch rate violate the Nyquist theorem and cause aliasing. Mirror frequencies have been identified by comparison to measurements at other repetition rates.

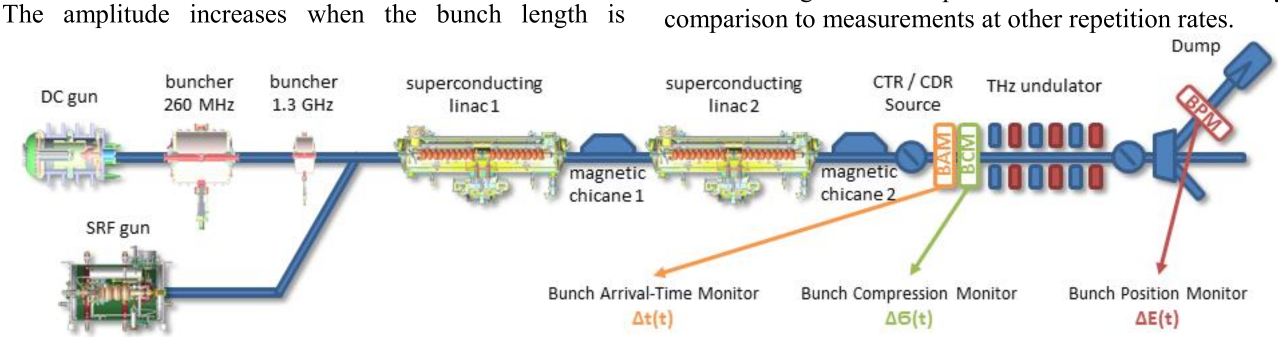

Figure 1: Schematic view on ELBE with two injectors, two superconducting accelerating cavies, magnetic chicanes for bunch compression and the THz sources. The diagnostics used to acquire the data for this contribution are highlighted, like bunch arrival time monitor, bunch compression monitor and energy dependent beam position monitor.

m.kuntzsch@hzdr.de

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NOISE ANALYSIS

BAM Results

The bunch arrival time monitor acquires the bunch information in time domain. By applying a Fourier transformation the information are transferred into frequency domain. Figure 2 shows the result for a 101 kHz beam at high compression in linear scale. Various fast spurs are visible above 15 kHz. The arrows mark frequency components which are also visible in the other measurements. The colors indicate spurs generated by the same noise components. For example 43 kHz as well as 17 kHz are introduced by an 84 kHz signal.

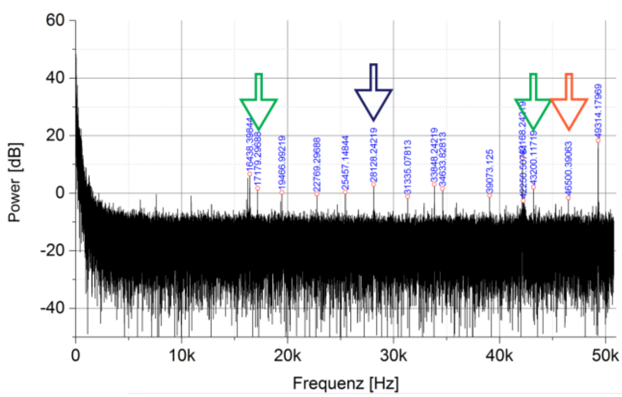

Figure 2: Bunch arrival time readout in frequency domain for a 101 kHz beam at 76 pC.

BPM Results

The energy dependent beam position measurement has been performed in parallel to the BAM measurements. Figure 3 shows the readout of the spectrum analyzer. 84 kHz and 28 kHz are mixed in the upper and the lower sideband of the 101 kHz carrier. The colors correspond to the same sources as in Fig. 2.

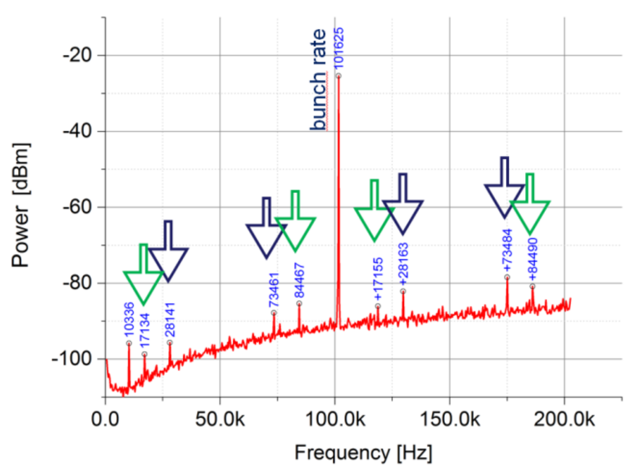

Figure 3: Power spectrum of the BPM readout. The 101 kHz carrier generated by the beam is modulated with repetitive spurs.

THz Power Spectrum

The THz power spectrum has been measured with a spectrum analyzer. The results shown in Fig. 4 indicate similar noise components as for the BPM and BAM measurements. In addition there is a major component visible at 56 kHz.

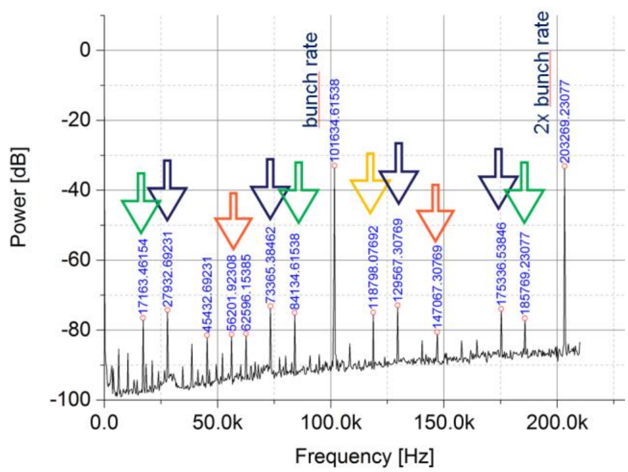

Figure 4: Power spectrum of the broadband THz source.

Summary of Analysis

The analysis of the three different beam diagnostic methods indicated similar noise components at 28 kHz, 56 kHz and 84 kHz which are all multiples of a common frequency. The equally spaced frequency components are most likely introduced by a single source. The amplitude of noise components varies from one method to other but they are always present. The frequency range of 28 kHz leads to the injector because fast fluctuation can barely be introduced by the superconducting cavities except for higher order modes.

IDENTIFICATION OF NOISE SOURCES

DC Gun and High Voltage Terminal

The DC gun at ELBE is using 235 kV to accelerate the electrons from the cathode. Figure 5 shows a schematic of the high voltage components. A resistor has been added to provide a measurement pickup to verify the voltage stability.

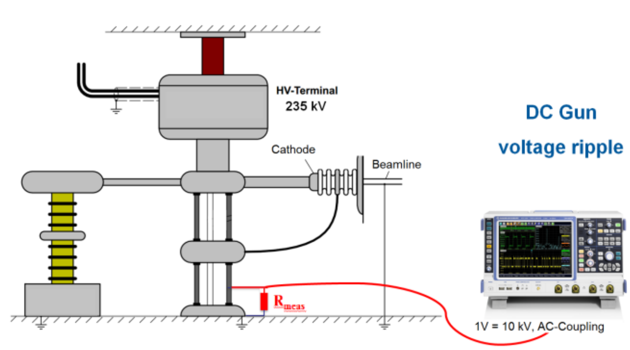

Figure 5: Schematic of the DC gun's high voltage terminal.

Results

The measurement revealed instabilities of the high voltage terminal, which can be seen in Fig. 6 and Fig. 7. The ripple has a continuous sine component at 56 kHz and repetitive spurs at 28 kHz rate. The amplitude ripple of more than 2000 volt represents 0.85 percent of the static value.

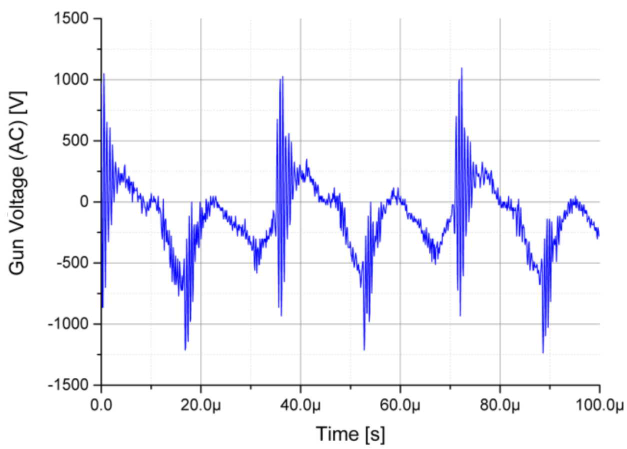

Figure 6: High voltage ripple in time domain with a 56 kHz sine component and bursts at 28 kHz rate.

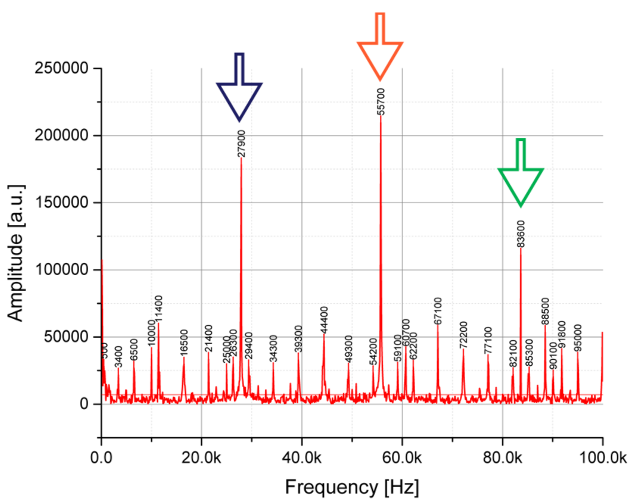

Figure 7: High voltage ripple in frequency domain. The measurement is dominated by 28 kHz and harmonic spurs

SUMMARY AND OUTLOOK

We demonstrated a combination of time and frequency domain measurements performed at ELBE. The high duty cycle enables a direct identification of noise sources indicated by their characteristic frequency. In particular the high voltage power supply for the ELBE DC gun has been revealed as one major contributor to the overall instabilities.

As a next step the high voltage power supply will be checked in order to identify the reason for the instabilities. The measured ripple which is outside of the device's specification might be due to damage caused by aging or radiation.

ACKNOWLEDGEMENT

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REFERENCES

[1] M. Gensch et al. "THZ FACILITY AT ELBE: A VERSATILE TEST FACILITY FOR ELECTRON BUNCH DIAGNOSTICS ON QUASI-CW ELECTRON BEAMS", Proceedings of IPAC14, TUZA02

[2] U. Lehnert et al., "BUNCH COMPRESSION OF THE LOW-ENERGY ELBE ELECTRON BEAM FOR SUPER-RADIANT THz SOURCES", Proceedings of IPAC2014, Dresden, Germany, TUPRO044

[3] C. Behrens et al, "UPGRADE AND EVALUATION OF THE BUNCH COMPRESSION MONITOR AT THE FREE-ELECTRON LASER IN HAMBURG (FLASH), Proceedings od IPAC2010, Kyoto, Japan, MOPD090

[4] M. Kuntzsch et al. "ELECTRON BUNCH DIAGNOSTIC AT THE UPGRADED ELBE ACCELERATOR: STATUS AND CHALLENGES", Proceedings of IBIC2013, Oxford, United Kingdom, MOBL3

[5] F. Loehl et. al., "Electron Bunch Timing with Femtosecond Precision in a Superconducting Free-Electron Laser", Physical Review Letters PRL 104, 144801 (2010)

[6] M. Kuntzsch et. al., "Status of the femtosecond synchronization system at ELBE", BIW2012, Newport News, USA, MOBP03

[7] P. Evtushenko et al., "PERFORMANCE OF THE ELBE BPM ELECTRONICS" , Proceedings of DIPAC2003, Mainz, Germany, PT15

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