SINGLE-SHOT LONGITUDINAL DIAGNOSTICS WITH THz RADIATION

H. Delsim-Hashemi[1], O. Grimm[2], B. Schmidt[2], P. Schmüser[1]

1: Univ. Hamburg, Germany, 2: DESY, Hamburg, Germany

Abstract

The longitudinal charge distribution in the electron bunches has a strong impact on the lasing process in a SASE FEL. For the 6 – 100 nm FEL *FLASH* at DESY, structures in the order of ten micrometers play a crucial role. The investigation of the longitudinal charge distribution in the electron bunches on a bunch-by-bunch basis is an important issue for optimizing the operation of the machine and improving its stability. This requires a single-shot device and is beyond the capability of existing spectroscopic diagnostic tools.

This paper introduces a new diagnostics tool based on THz spectroscopy of coherent transition radiation (CTR). A novel spectrometer has been designed which permits to analyze the radiation of single electron bunches in a broad spectral range and with high resolution.

Preliminary measurements with this spectrometer in both scanning mode and single-shot mode are presented and discussed.

INTRODUCTION

FEL facilities in the VUV and X-ray regime require kA peak currents which are usually achieved by several stages of bunch compression. The longitudinal charge distribution of the compressed bunches has to be measured with high precision in order to fine-tune the off-crest phase in the accelerating section preceding the magnetic bunch compressor chicanes and to optimize the SASE performance. Two types of diagnostic methods are currently being applied at FLASH: time-domain techniques by means of streak cameras or electro-optic detection, and frequency-domain techniques based on Martin-Puplett interferometers. The existing interferometers operate in the scanning mode and determine the average pulse shape of many thousand bunches. They are intrinsically unable to yield information on single bunches.

The new single-shot spectrometer uses diffraction gratings as dispersive elements and an array of pyroelectric detectors with multi-channel readout. This device is still in the construction phase. Exploratory measurements with the first stage, containing eight channels, will be presented.

The data have been taken at a new THz beam-line [1] which transports coherent transition radiation (CTR) or coherent diffraction radiation (CDR) over a 19 m distance from the accelerator into an experimental hut. The beam-line is evacuated to a pressure below 0.1 mbar to avoid THz absorption in humid air. The radiation is coupled out of the ultra high vacuum environment of the linac into the beam-line through a CVD diamond window which features wavelength-independent transmission from 6 micrometers up to several millimetres. The radiation screens of the THz beam-line are installed at the 140 m position of the FLASH linac, downstream of the final bunch compressor and the last accelerator module. Thereby the bunch shape at the entrance to the undulator can be determined.

OPERATIONAL DIAGNOSTIC TOOLS AT FLASH

Martin-Puplett Interferometer

Two Martin-Puplett interferometers are currently operational at FLASH. The first one is equipped with DTGS pyroelectric detectors and is used to analyze coherent synchrotron radiation at the magnetic chicane of the first bunch compressor. The second interferometer is equipped with Golay cells and detects coherent diffraction radiation at the second bunch compressor.

Bunch Compression Monitor (BCM)

Pyroelectric detectors are mounted behind the bunch compressors looking at the integrated diffraction radiation intensity in the range from 100 GHz and a few THz. The signal amplitude depends on the degree of compression. While such a device is a good tool for an approximate tuning of the off-crest phase in the accelerating cavities preceding the bunch compressor chicane, the information obtained from it is not sufficient to adjust the optimum bunch compression and distinguish different compression schemes.

GRATING SPECTROMETERS

The coherent radiation of the compressed bunches in the FLASH linac covers a wide wavelength spectrum from the millimetre range down to a few micrometers. An efficient way to disperse such a broad-band radiation to different detection channels is based on diffraction gratings. Reflectance blazed gratings can be designed to yield very efficiency (~90%) while transmission gratings reach efficiencies of about 20%.

Types of Grating Spectrometers at FLASH

The principles of grating based spectrometers as tools for longitudinal diagnostic are described in reference [2]. New developments include a rotating mirror spectrometer (Fig. 1) and a multi-channel spectrograph (Fig. 2).

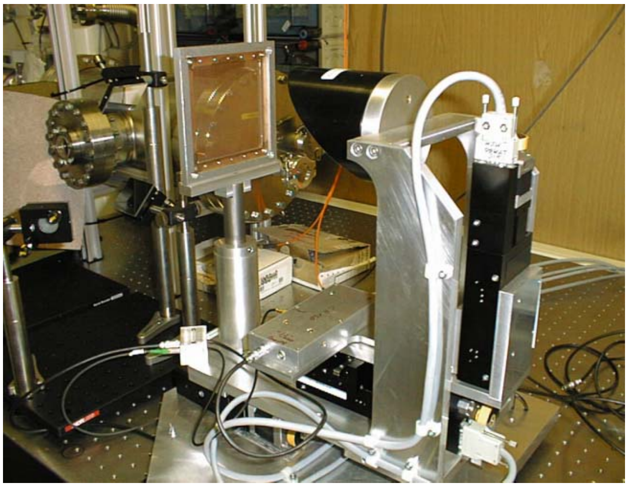

Figure 1: Rotating mirror spectrometer with transmission grating.

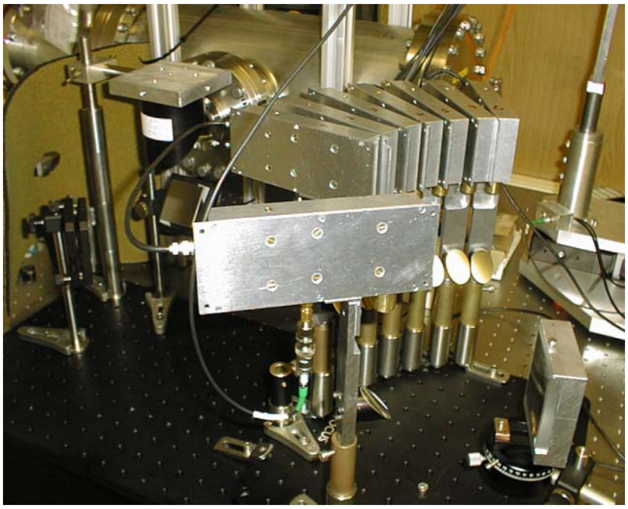

Figure 2: Multi-channel spectrograph with reflectance grating.

Measurements with a Rotating Mirror Spectrometer

The spectrometer shown in Fig. 1 works in the scanning mode. Using this spectrometer with different gratings, the overall CTR spectrum emitted by the finally compressed bunches in the FLASH linac has been recorded. Preliminary data are shown in Fig. 3. A strong rise towards short wavelengths is observed with a gap around 5 µm which is caused by absorption in the CVD diamond window, see Fig. 4. The general problem of all scanning devices becomes especially pronounced in this wavelength regime since the spectral intensity fluctuates by large factors from bunch to bunch.

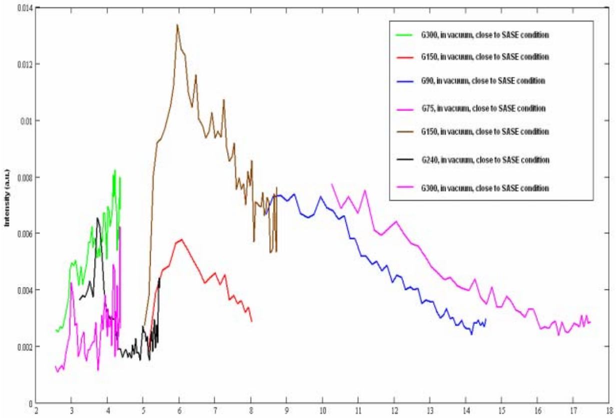

Figure 3: Measured spectrum of CTR emitted by the finally compressed electron bunches in the linac of FLASH.

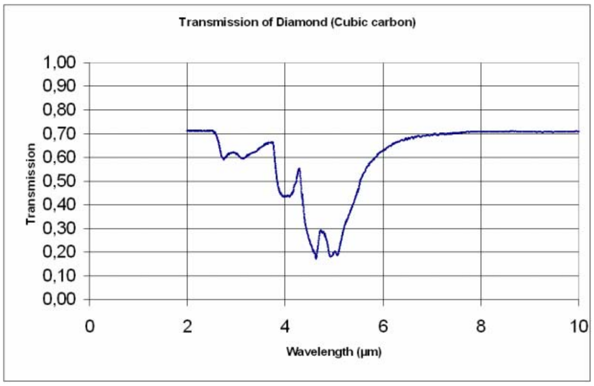

Figure 4: Transmission of the diamond window at the entrance of the THz beam-line.

The well-known transmission curve of diamond can serve as an additional check on the correct wavelength calibration of the spectrometer. After correction for the transmission losses we obtain the spectrum shown in Fig. 5. These very preliminary data can be used to estimate the time profile of the bunches. Two possible profiles are shown as an inset to Fig. 5 to demonstrate the discriminatory power of the method. The leading peak in the bunch seems to be as short as 15 fs.

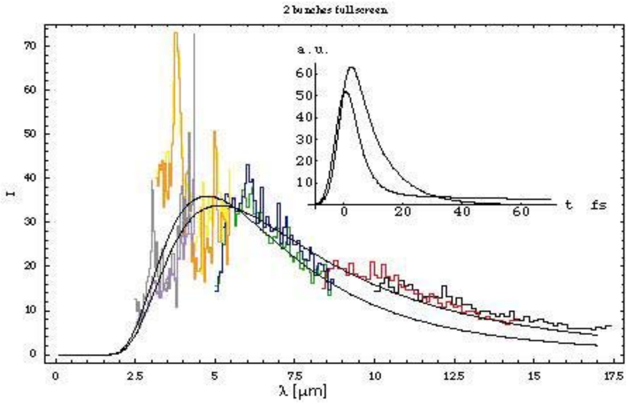

Figure 5: Preliminary CTR spectrum and corresponding bunch profiles.

Correlations Between Spectroscopic Signals and FEL Pulse Energies

The single-shot spectrometer has been used to study the correlation between the energies of the FEL pulses (called SASE signals) and the amplitudes of the CTR pulses in different wavelength channels. The FEL pulse energies are measured with an ionisation chamber called "gas monitor detector". In SASE operation, one observes rather large fluctuations of the FEL pulse energies which are partly due to the intrinsic fluctuations in the SASE process itself but also due to shot-to-shot variations in the electron bunch shapes. In Fig. 6, we show the correlation between the "SASE" signals and the signals of the bunch compression monitor BCM. The optimum SASE signal is observed for intermediate pulse heights in the BCM while the SASE signal drops to zero for small or large BCM signals.

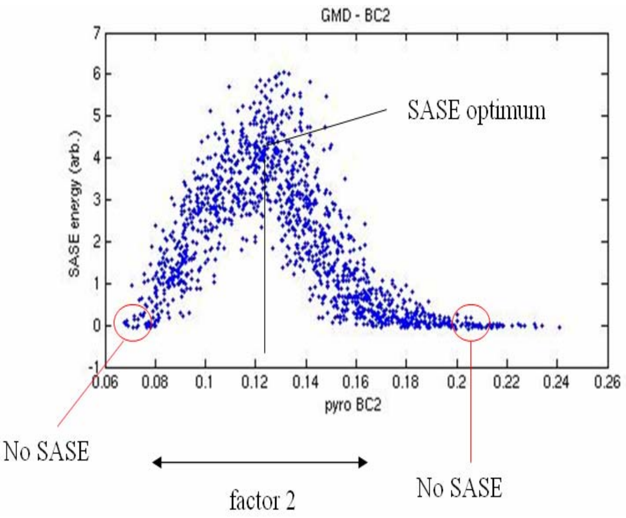

Figure 6: SASE signal versus BCM signal for 5000 successive bunch trains.

Correlation plots between the SASE signals and the signals in different wavelength channels of the single-shot spectrometer are presented in Figs. 7 and 8. The analysis of these data is still underway.

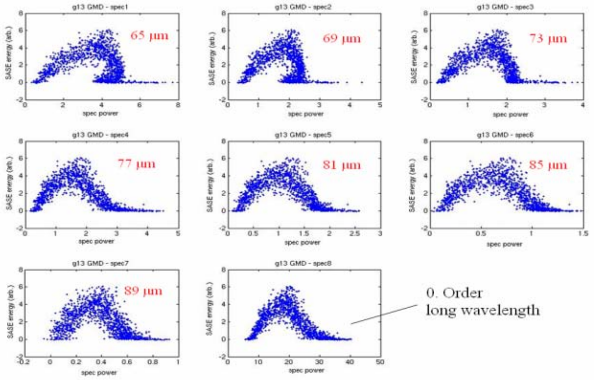

Figure 7: SASE signal and spectrograph signal correlation in the 65 to 90 micrometer range.

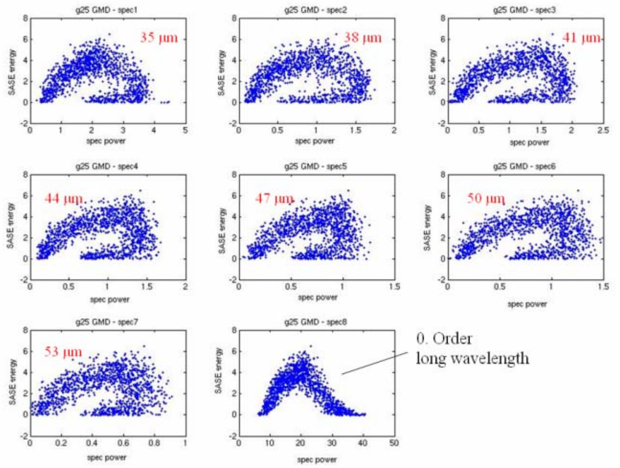

Figure 8: SASE signal and spectrograph signal correlation in the 30 to 50 micrometer range.

These very first measurements show the interesting effect that for bunches producing overall *more* than 'optimum' coherent radiation (over-compressed bunches), nevertheless the content in short wavelength ranges is strongly reduced and the resulting SASE energy basically drops to zero.

CONCLUSION

It has been demonstrated that a single-shot spectrometer based on reflectance blazed gratings and multi-channel signal detection can cover a large fraction of the coherent transition radiation spectrum of individual electron bunches. In the next stage of the spectrometer more gratings and readout channels will be incorporated to enable measurements of the full CTR spectrum in single-shot mode.

REFERENCES

[1] S. Casalbuoni et al., *Coherent Transition and Diffraction Radiation, Part II: The THz Beam line at the VUV-FEL,* TESLA-FEL Report 2005-04

[2] H. Delsim-Hashemi et. al., *Broadband single shot spectrometer*, Proceedings FEL2005