SINGLE-SHOT LONGITUDINAL DIAGNOSTICS WITH THZ RADIATION AT THE FREE-ELECTRON LASER FLASH

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Abstract

The longitudinal charge distribution in the electron bunches has a strong impact on the lasing process in a Free-Electron Laser based on the principle of Self Amplified Spontaneous Emission of radiation. For the ultraviolet and soft X ray FEL FLASH at DESY, structures in the range of ten to hundred 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 bunch compression and improving the performance of the machine. This paper introduces a new tool for longitudinal diagnostics based on THz spectroscopy of coherent radiation. 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 are presented.

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. 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 pyro-electric detectors with multi-channel readout. Exploratory measurements with the first stage, containing thirty channels will be presented.

GRATING SPECTROMETER

The coherent radiation of the compressed bunches subjected to a radiation process in the FLASH linac covers a wide wavelength spectrum from the millimeter range down to a few micrometers. Diffraction gratings are well suited to disperse broad-band radiation to different detection channels. The principles of grating based spectrometers as tools for longitudinal diagnostic are described in reference [1]. These principles are applied in several devices that are described in [2] and [3] or will be explained in this paper.

Advanced bunch compression monitor

As it is described in reference [3], a multi stage reflectance blazed grating spectrometer is used to study bunch compression versus machine parameters. In the following comes an example. It is known that the off-crest phase φ in the first acceleration module ACC1 has a strong influence on the longitudinal bunch profile that is obtained when the bunches have passed the two magnetic chicanes. Empirically it is found that the SASE efficiency depends very critically on φ and reaches its maximum at $\varphi \approx -5^\circ$ to -6°. A phase scan around this value is shown in Fig.1. The signal of the gas monitor detector (GMD), measuring the pulse energy of the FEL light, exhibits a pronounced maximum at φ = -5.7° with a width of $\pm 0.2^\circ$. The coherent transition radiation intensities in various wavelength channels are also plotted in Fig.1. The remarkable observation is that the intensity for short wavelengths (20 to 75 μm) exhibits a strong peak in the region of maximum SASE intensity while the intensity of long wavelengths has a monotonic increase towards more negative phase.

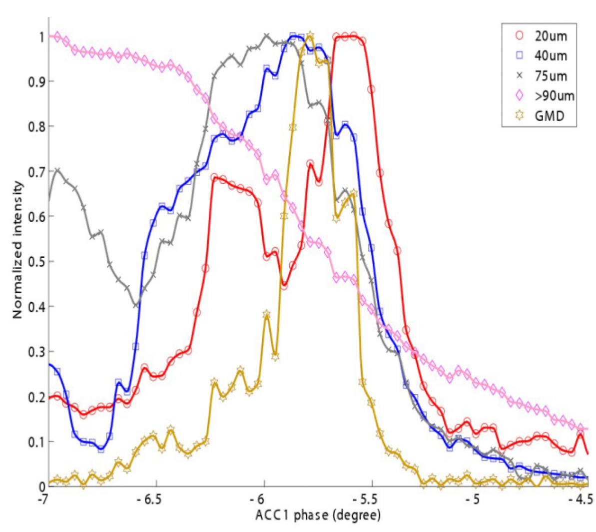

Figure 1: Amplitude of the SASE FEL signal as a function of the off-crest phase φ in the first acceleration module. Also the intensity of coherent transition radiation for wavelengths of $20\pm1\mu m$, $40\pm2\mu m$, $75\pm4\mu m$ and for $\lambda > 90\mu m$ is shown. Distributions are individually normalized to a maximum value of 1.

Spectrograph

Here a single shot spectrometer that gives the ultra broadband spectra of coherent radiation on a shot to shot basis is called spectrograph. As it was described in [1] a spectrograph is composed of three main components, one that disperses the polychromatic radiation, one that focuses the dispersed radiation to spatially different coordinates dependent on wavelength without mix-up and the detector system. The first two issues were covered and explored in [2] and [3]. The most new achievement is the development of a fast 30 channel detection system based on pyro-electric sensors, Fig. 2.

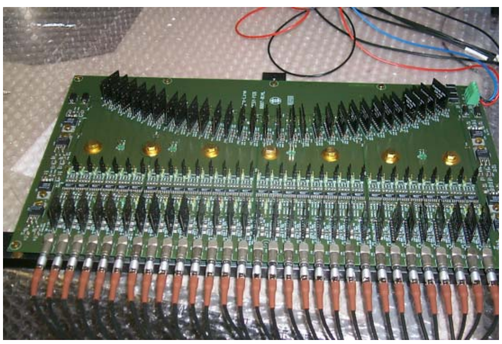

Figure 2: The 30 channel pyro line detector is equipped with fast read out electronics and pyro sensors with broadband smooth response function. The sensitivity is about 300 pJ (5 times noise level) for 1µm < λ < 1mm, [4].

Two types of single stage spectrographs based on Transmission Grating (TG) and Reflectance Blazed Grating (RBG) have been successfully tested.

A TG base spectrograph can cover a rather large range of wavelengths in a single stage. It should be noticed that with a single stage TG spectrograph we will cover the entire interesting wavelength range from 50 to 300 μm, with only two stages the spectra up to 1.8 mm could be derived, Fig. 3. Fig. 4 shows a sequence of 600 subsequent single shot spectra.

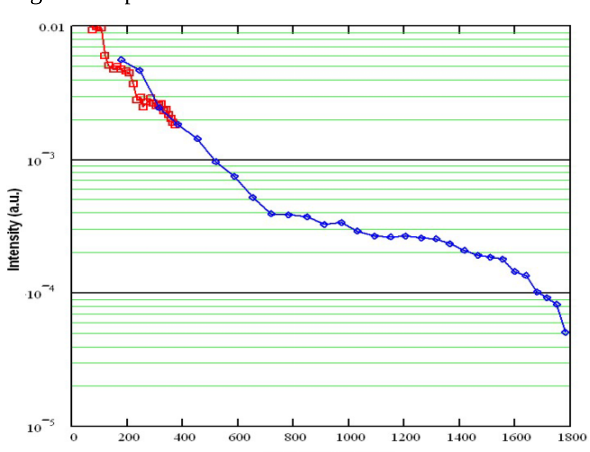

Figure 3: The averaged combined spectra recorded by stages with 2.5 and 0.5 line per mm.

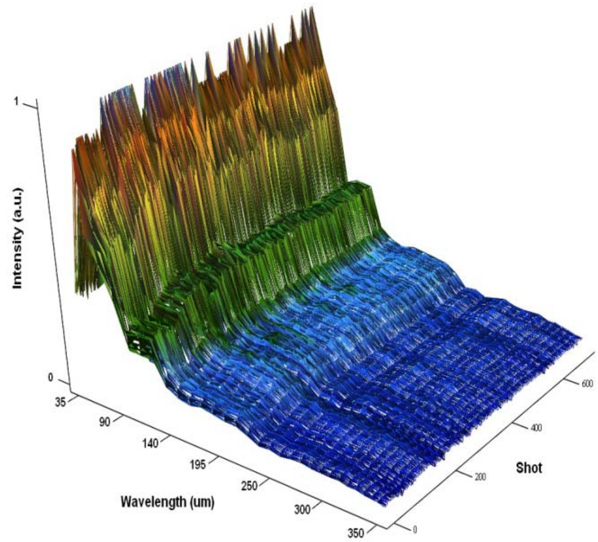

Figure 4: Recorded spectra by using a transmission grating with 2.5 lines per mm.

Reflectance blazed grating have a limited free spectral range of about a factor of two but offer much better resolution and efficiency and can be staged [1]. From the previous studies it is clear that the most relevant part of the spectra for the FLASH machine operation in SASE mode is about 10 to 100 μm. One of the measured spectra in this regime is shown in Fig.5. A combined plot of measured spectra on different regions, averaged over many shots, is shown in Fig. 6.

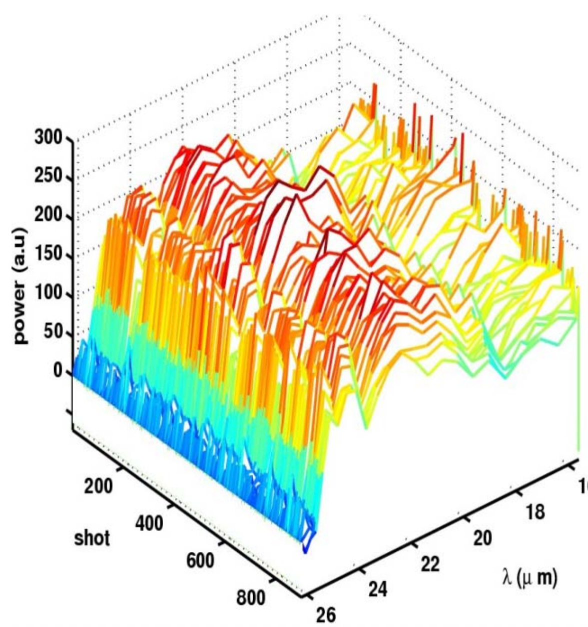

Figure 5: About 900 subsequent shots measured with reflectance grating of 50 lines per mm during SASE operation.

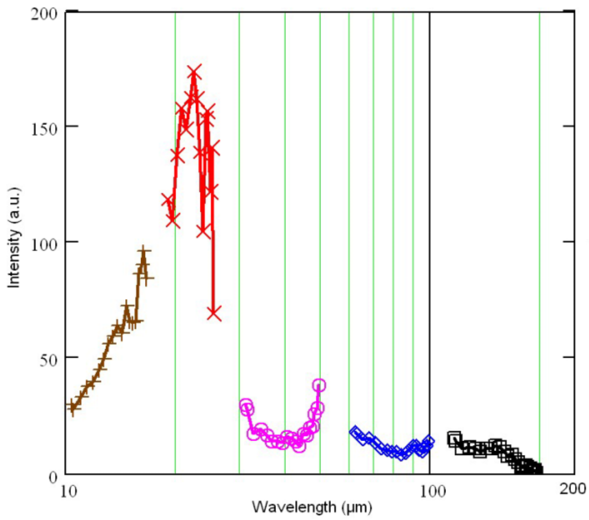

Figure 6: The averaged combined spectra recorded by different RBGs. Full coverage of interesting range of the spectra for FLASH electron bunches requires 5 stages of RBG base spectrograph.

Fig. 7 shows a series of single shot spectra in the wavelength range from 30 to 50 μm recorded while the phase of first accelerating module was changed by ~10 degrees. The spectra shows a very pronounced peak at the phase of operation for optimum SASE.

CONCLUSION

We have demonstrated that single-shot wavelength-selective spectroscopy of coherent radiation is possible. The described spectrograph can give, on a shot to shot basis, information on very short structures of the electron bunches which is not possible by other techniques and can be used for fast feedback systems.

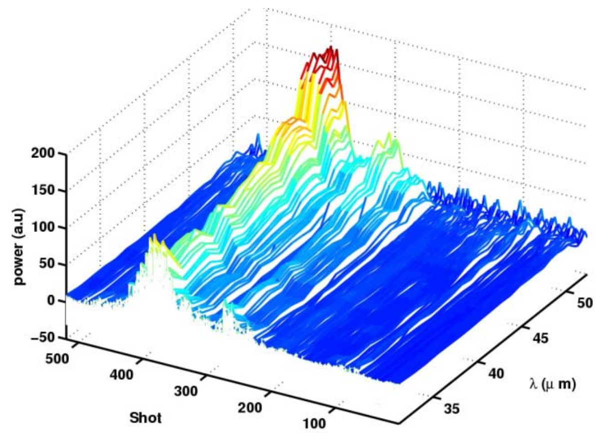

Figure 7: Plotted is the variation of the spectra in one of the stages of reflectance blazed grating spectrograph (with 25 lines per mm) when phase of the first accelerating module changed over ~10 degrees. The peak coherent radiation intensity corresponds to operational condition for optimum SASE.

REFERENCES

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