BUNCH DIAGNOSTICS WITH COHERENT INFRARED UNDULATOR RADIATION AT FLASH

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The Free-Electron-Laser in Hamburg (FLASH) at DESY has been complemented by an electromagnetic infrared undulator as a new tool for analysing the longitudinal profile of the short electron bunches characteristic for FLASH using coherent diagnostic techniques. This undulator has a maximum K-Value of 44 corresponding to a maximum wavelength of 200 µm at an electron energy of 500 MeV. For the characterization of the emitted radiation and for the analysis of correlations between machine or undulator parameters and undulator spectra, an experimental set-up has been developed and installed in the FLASH Experimental Hall containing a dispersive spectrometer as a main instrument. The spectrometer is designed for THz spectra using reflective blazed gratings as dispersive elements and a pyroelectric detector. The final goal is the reconstruction of the longitudinal bunch shape by tuning the undulator through the wavelength range of the electromagnetic device and measuring the intensity of the infrared radiation.

INTRODUCTION

The Free-Electron-Laser in Hamburg (FLASH) is a high-gain FEL user facility at DESY operating in the photon wavelength range from vacuum ultra-violet to soft x-rays. It is driven by a superconducting linac and the generation of the FEL radiation is based on the SASE process. In autumn 2007 FLASH reached its design goals being an electron energy of 1 GeV and lasing down to 6.5 nm photon wavelength [1].

For a high-gain FEL like FLASH the energy of the electron beam defines the photon wavelength assuming a fixed gap of the undulator. In addition, the longitudinal charge distribution within the bunch and the transverse electron beam size are crucial factors within the lasing process of FELs. This is based on the dependence of the *FEL-gain* on the peak current via the *gain length* L_G which is defined as

$$L_G = C\gamma \left(\frac{\sigma_t^2}{I_0}\right)^{1/3}$$

where C is a constant determined by the undulator, γ the relativistic factor, σ_t the transverse RMS size of the bunch and I_0 the peak current of the charge distribution. Therefore, a small beam size (or emittance) and a high peak current are required to obtain a short gain length necessary for high-gain FELs.

In order to obtain the high peak current, the electron bunch needs to be compressed. For a proper analysis of the FEL process and operation, longitudinal bunch diagnostics with high resolution for sub-picoseconds bunches are required.

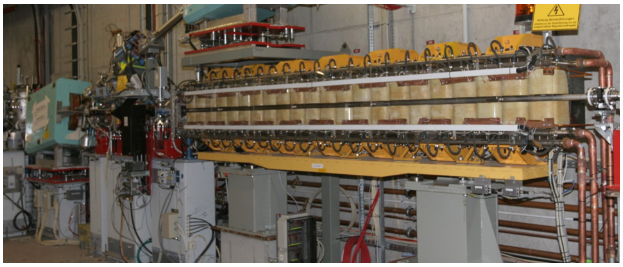

Figure 1: The infrared undulator installed between the FEL and the electron dump.

Since summer 2007 there is a new tool for longitudinal bunch diagnostics at FLASH. Behind the FEL, an electromagnetic infrared (IR) undulator has been installed producing radiation from 1-200 µm for an electron beam energy of 500 MeV [2]. The aim is to reconstruct the longitudinal bunch profile by tuning the undulator to certain wavelengths and measuring the intensity at these points. The advantage compared to the broad band techniques is that the radiation intensity produced within the IR undulator at a certain wavelength is emitted within a small band width.

THE EXPERIMENT

The first step towards the usage of the new infrared undulator as bunch diagnostic tool has to be the spectral investigation of the source which is presented in this paper (for detailed information see [3]). For this purpose a spectrometer has been designed and implemented in an experimental station at the new infrared beamline of FLASH.

The Undulator

The infrared undulator is implemented in the accelerator tunnel between the FEL undulators and the electron dump (see fig. 1). It is an electromagnetic device with 44 poles, a gap of 40 mm and a period length of 40 cm. With a maximum current of 435 A a magnetic field of 1.2 T can be produced.

The wavelength of the emitted radiation can be calculated by the undulator equation

$$\lambda_1 = \frac{\lambda_U}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\Theta^2\right) \tag{1}$$

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where the subscript 1 indicates to the first harmonic called the *fundamental*. λ_U is the undulator period and Θ the observation angle. K is the undulator parameter which is defined as

$$K = \frac{eB_0\lambda_U}{2\pi mc^2}$$

with B_0 as the peak magnetic field of the undulator.

The Beamline

The light produced by the electron bunch within the IR undulator is transported to the experimental hall by a special infrared beamline.

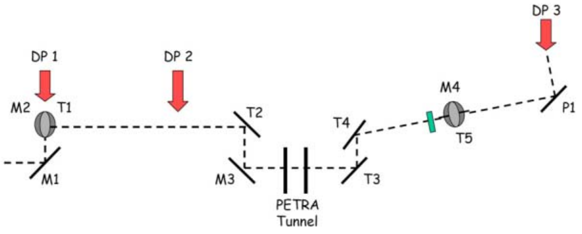

Figure 2: The infrared beamline with its diagnostic ports (DP).

The specialty of this beamline is its ability to transport radiation from 1-200 µm without destroying the picosecond time structure of the pulses [4]. The challenge of the beamline construction is the large divergence of the infrared beam with various unavoidable apertures at the same time. Several toroidal mirrors are used as focusing elements to transport the beam through the vacuum chamber.

The beamline has five diagnostic ports where the radiation can be coupled out (see fig. 2). The second and third one is reserved for electron beam diagnostics whereas the other ports are used for photon diagnostics.

The Spectrometer

For spectral investigations of the infrared source a scanning spectrometer has been designed using reflective blazed gratings as dispersive elements and a pyroelectric detector as infrared sensor. The principle of the device is based on the concepts from [5]: The incident infrared beam has to pass a filter grating before it hits on the dispersive element to eliminate higher orders. A rotatable arm with a focusing mirror scans the dispersive section, deflecting the spectral components of the radiation on the detector.

The Experimental Station

The spectrometer has been implemented in an experimental station at the third diagnostic port of the infrared beamline. As shown in fig. 3, the infrared radiation passes a preparative optical setup before it enters the spectrometer. This is necessary, because the spectrometer design requires a beam which has

- A long a Rayleigh length and a waist behind the focusing mirror of spectrometer.
- A transverse spot size on gratings below 25 mm.
- A horizontal polarization.

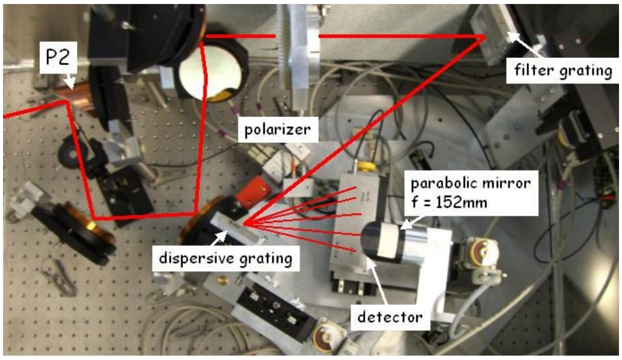

Figure 3: The experimental station: Radiation passes preparative optics before it enters the spectrometer.

The first requirement has been achieved with two off-axis parabolic mirrors used as a Gaussian telescope. The result is a beam with quasi-parallel behavior as required for the spectrometer.

The polarization of the infrared radiation is vertical at the diagnostic port. Thus, it needs to be changed to horizontal polarization with help of a periscope composed by two planar mirrors. To make sure that no vertical polarized radiation arrives at the filter grating, a polarizer is additionally installed in between the periscope and the filter.

The whole setup of optical elements and spectrometer is enclosed by a plexiglas box strengthened with aluminium plates for radiation protection. The box is purged with nitrogen to remove the water vapour which highly disturbs the spectral analysis.

THE RESULTS

The spectra taken with the spectrometer are all corrected for detector response and efficiency of the dispersive element. Additionally, the background measured with the undulator being at zero current is subtracted.

Wavelength Shift

The first measurements were done for an investigation into the first harmonic of the undulator radiation. The expected wavelength is calculated from the previously measured K-value and the electron energy. Fig. 4 shows the fundamental spectrum with the undulator being tuned to 85 µm. As one can get from a fit, the fundamental is shifted to 91.8±0.4 µm(±0.7 µm) where the first error is the statistical error due to the fit and the second one is the systematic error. This corresponds to a shift of $8\% \pm 1\%$ towards longer wavelengths.

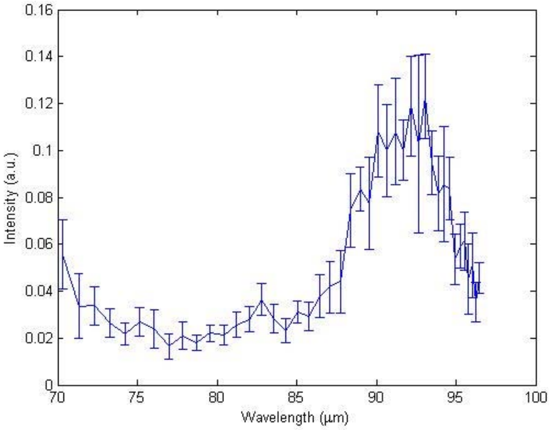

Figure 4: Spectrum taken with undulator tuned to 85 μm. The fundamental is shifted by 8% ± 1% towards longer wavelengths.

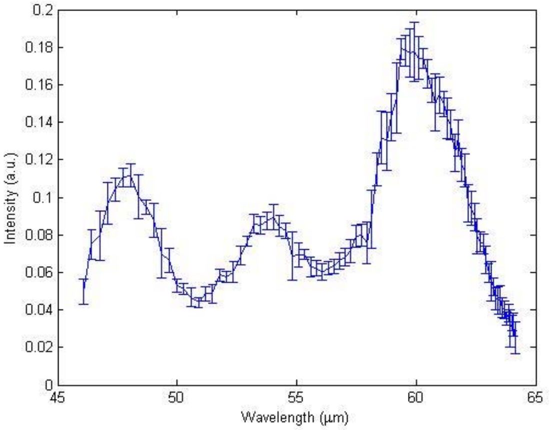

Figure 5: Spectra taken with undulator tuned to 55 μm. At this machine status, spectrum shows additional peaks besides the fundamental.

Considering equation (1), there are several parameters which could cause a wavelength shift. The focus of the analysis has been on the electron beam energy and angle of observation. So far, no clear picture could be drawn for a complete understanding of the shift. Further investigations are planed.

Multiple Peak Spectra

During three measurement shifts in a row, the spectra of the fundamental have shown additional peaks being of the same width as the fundamental. These peaks stick to the first harmonic and are dependent on the phase of the acceleration cavities which excludes an instrumental effect. Recent measurements could not reproduce such spectra, however, which requires a detailed investigation of the circumstances during these shifts.

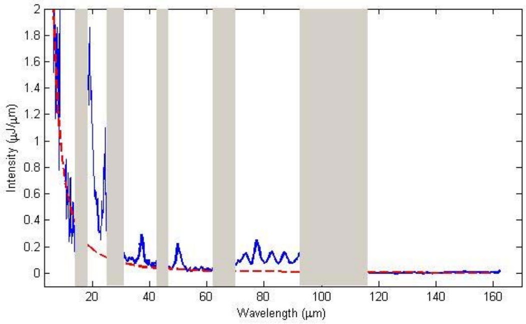

Figure 6: Full spectrum taken with undulator tuned to 140 μm. It shows an increasing background towards shorter wavelengths, which comes from the dump magnet as the simulation of the dump spectrum (dotted) shows.

Full Scan

Fig. 6 shows a full spectrum with undulator tuned to 140 μm. A large background is observable increasing towards shorter wavelengths. Measurements determine the last dipole in front of the electron dump as the main source for this background intensity. Especially in the short wavelength regime the background needs to be subtracted from spectra for an appropriate analysis.

Interestingly, mostly even higher harmonics occur whereas dominant odd harmonics are expected. This is currently not understood.

CONCLUSION

The spectra of the new infrared undulator at FLASH are highly dependent on the machine parameters. All measurements show that a change in the machine setup leads to a change in the shape of the spectrum. Complicated structures were observed which are not completely understood. Because a good understanding of the spectra is required for electron beam diagnostics, further measurements are necessary.

REFERENCES

[1] S. Schreiber, *FLASH*, Talk within FLASH Tutorial (2007), http://flash.desy.de/e409/e2219/e2224/flash-overview-cp.pdf.

[2] V. Borisov et. al., *Simulation of Electromagnetic Undulator for Far Infrared Coherent Source of TTF at DESY*, in *Proceedings of EPAC 2006* (Edinburgh 2006), p. 3595-3597.

[3] A. Willner, *Investigations into the FLASH Infrared Undulator as an Electron Beam Diagnostic Tool*, TESLA-FEL Report **2008-04** (Hamburg, 2008).

[4] U. Fruehling, *Arbeitsbericht über den Zeitraum vom 01.10.2005 - 11.06.2007*, internal paper (Hamburg, 2006).

[5] H. Delsim-Hashemi et. al., *Broadband Single Shot Spectrometer*, in *Proceedings of the 27th International FEL Conference 2005* (Stanford, 2005).