DESY Summer Student Program 2010

Report

by Aleksandra Wandzilak

Spectral analysis of high-harmonics content of radiation produced by FLASH at DESY

Supervisor: Natalia Guerassimova

Abstract

The free-electron laser at the DESY research centre in Hamburg (FLASH) offers numerous research possibilities. To analyse the characteristics of the radiation generated by the FLASH laser, an upgraded spectrometer was used, which features a sensitivity in the 2-40 nm region. By studying the performance of the spectrometer, information about the harmonic components of the beam and their intensities was obtained which can be used in analysing the measurement data obtained from samples.

Table of contents

1. Introduction

1.1. FLASH

The **f**ree-electron **las**er built in 2005 at the DESY research centre in **H**amburg (FLASH) produces extremely bright ultra-short pulses in the extreme ultraviolet (XUV) region of 5-47 nm. The upgrade of the facility in 2009 increased this range to levels below 5 nm in the first harmonic. As a result of the stochastic nature of the radiation, individual radiation pulses differ in their intensity, temporal structure and spectral distribution. For this reason the images were statistically analysed to allow interpretation of the results obtained.

A free-electron laser uses a beam of relativistic electrons (whose speed is close to that of light) which pass through an array of magnets (called undulator) along a sinusoidal path, thus releasing photons which are all in phase with those emitted earlier, and thus add together coherently.
To study the radiation produced by the FLASH laser, a flat field spectrometer with spherical varied-line-spaced (SVLS) gratings was used. The spectrometer employs diffraction grating to produce an image recorded by the CCD camera.

1.2. Spectrometer

A schematic diagram of the spectrometer is shown in Fig. 1. Light enters the spectrometer's high-vacuum chamber through a slit and falls on one of the two spherical varied-line-spaced (SVLS) diffraction gratings, with 1200 or 2400 grooves per mm. The gratings are positioned on a turntable so that they can be easily switched. The light diffracted by the grating produces an image on the focal curve which for a particular incident angle can be fitted by a line. The image is recorded by a detector - a charge coupled device (CCD) camera which converts light into electrical signal proportional to the light brightness. The camera consists of numerous CCDs – semiconductor gates placed on a substrate - which collect and store the electric charge, each representing a pixel of the image.

The limited size of the camera matrix relative to the size of the studied section of the focal plane makes it necessary to moves it along the straight line which best tits the focal plane to record the required diffraction image.

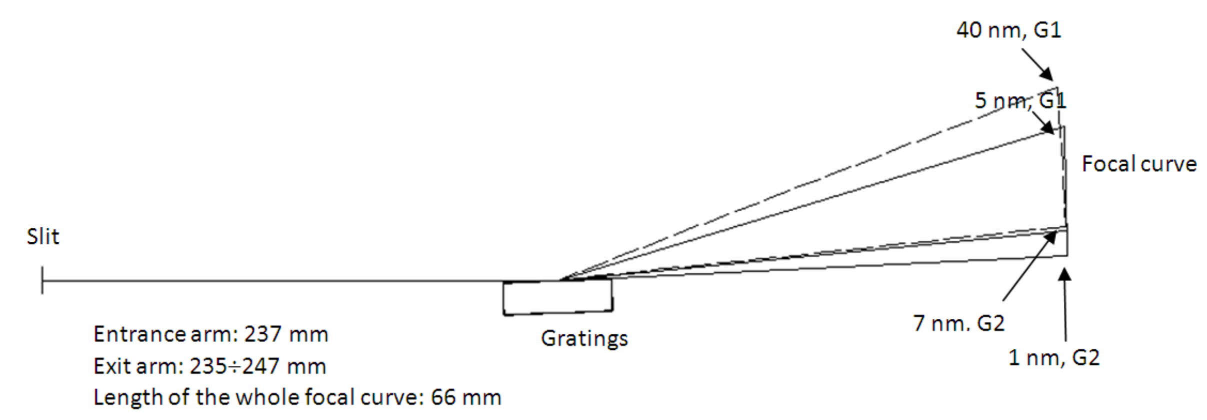


Fig. 1. Diagram of the spectrometer

2. Experimental part

The light beam undergoes diffraction on the grating. The image will appear at various points of the focal curve, depending on the wavelength. The detector will measure the beam intensity at these points.

Fig. 2 shows an example image of harmonic components of the beam recorded by the detector.

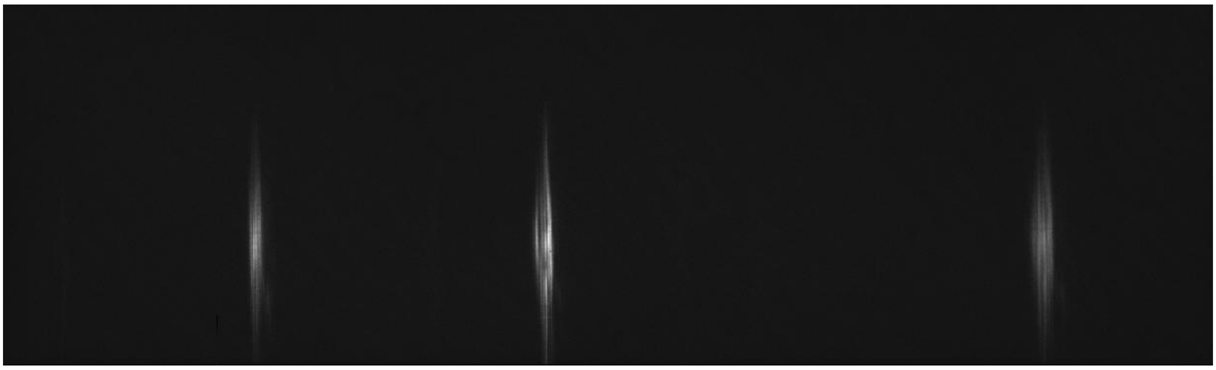


Fig. 2. An example image recorded by the CCD camera

Next, the images from all pixels are added up on a horizontal axis and thus integrated image is shown in Fig. 3 as a sum of intensities at various points. Each image recorded by the CCD camera was processed this way.

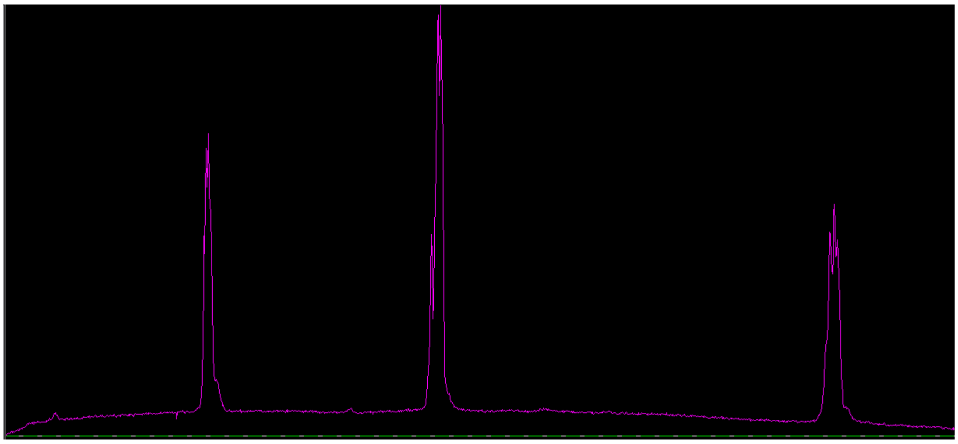
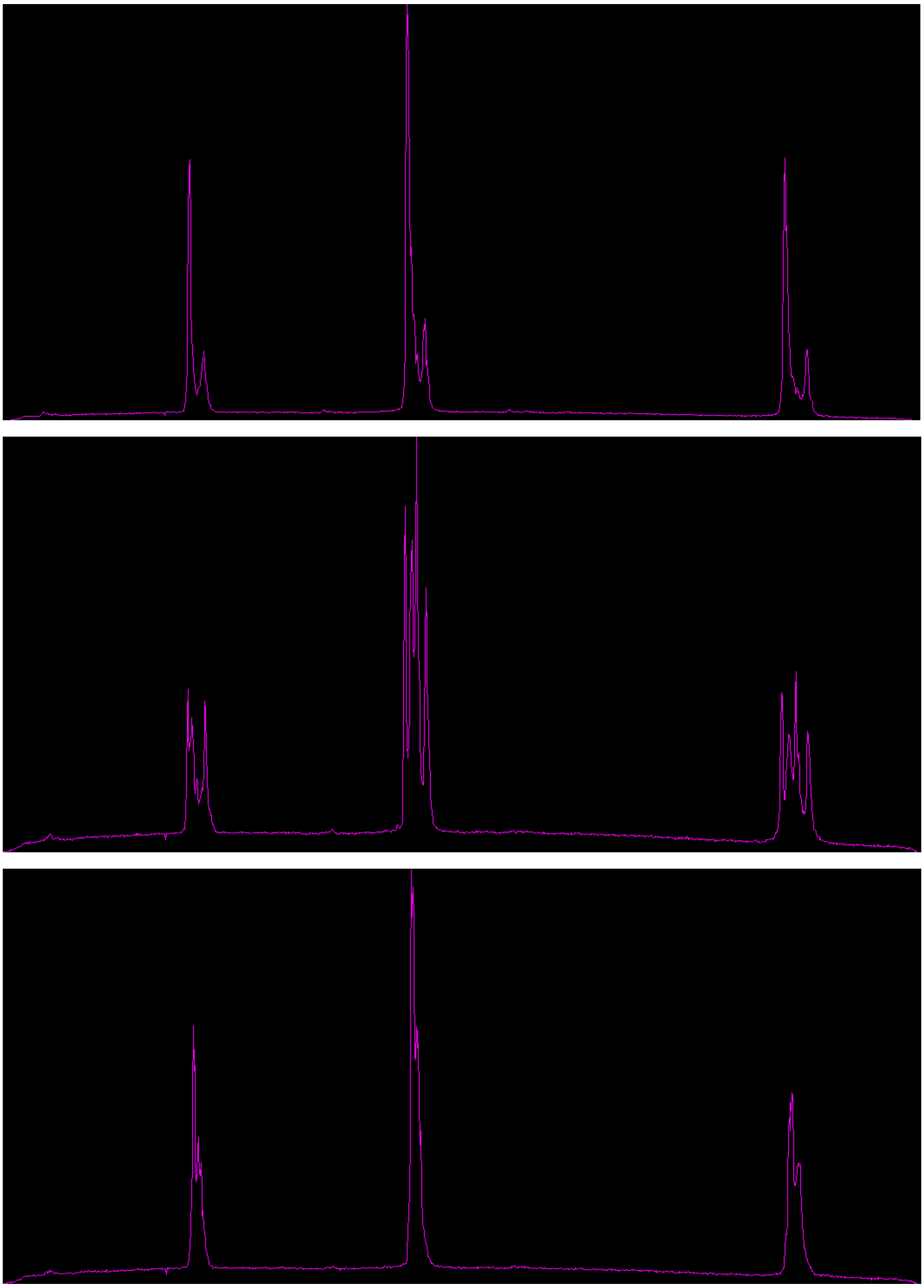


Fig. 3. A CCD camera image presented as a dependence of beam intensity on the position of the CCD matrix.

A femtosecond laser emits radiation in pulses. Individual pulses differ from each other. As a result, individual images from the CCD camera obtained for the same set of parameters at various moments differ from each other (Fig. 4).



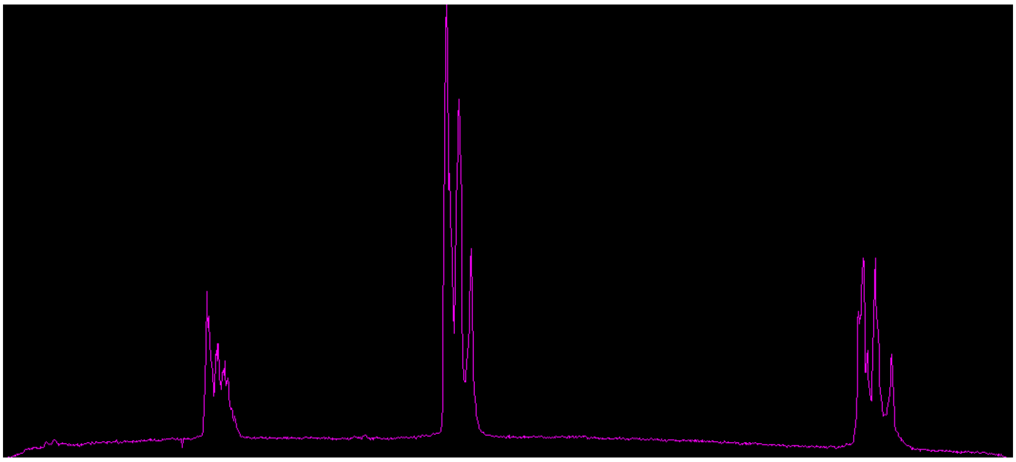


Fig. 4. Changes in the CCD matrix noted for individual pulses

Consequently, to obtain data that can be used for further analysis, for each set of parameters many shots have to be taken and then averaged.

As the surface area of the detector is much smaller than the focal plane where the image was formed, the detector had to be moved along the entire plane.

The light incident on the diffraction grating underwent both diffraction and interference. The diffraction provided information about individual harmonic components of the beam, as the harmonics were diffracted depending on their wavelength and thus recorded at different points of the screen.
Imposed on this picture was the result of interference: a series of interference lines can be seen on the image.

To analyse individual components, we had to assign wavelengths to individual points in on the focal plane.

Fig. 5. and Fig. 6 show images recorded at the focal plane for two diffraction gratings : G1200 and G2400. The G2400 grating has a greater number of grooves and consequently is better for shorter wavelengths.

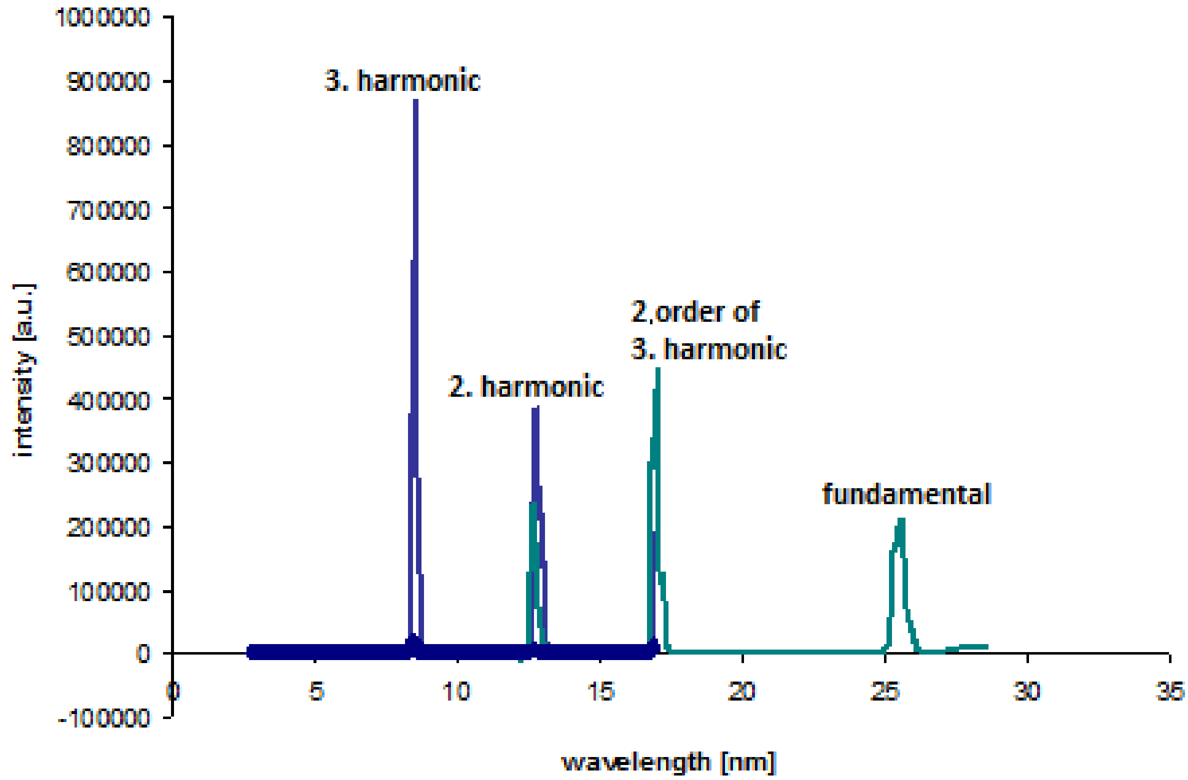


Fig. 5. The 1200 grating

Fig. 5 shows the first, second and third harmonics whose wavelength are two and three times shorter, respectively, than the fundamental frequency. Higher diffraction orders are clearly seen in images obtained with 1200 l/mm grating. Thus one can see 3rd harmonic in second diffraction order. The second diffraction order of the second harmonic and the third diffraction order of the third harmonic overlap with the fundamental wavelength.

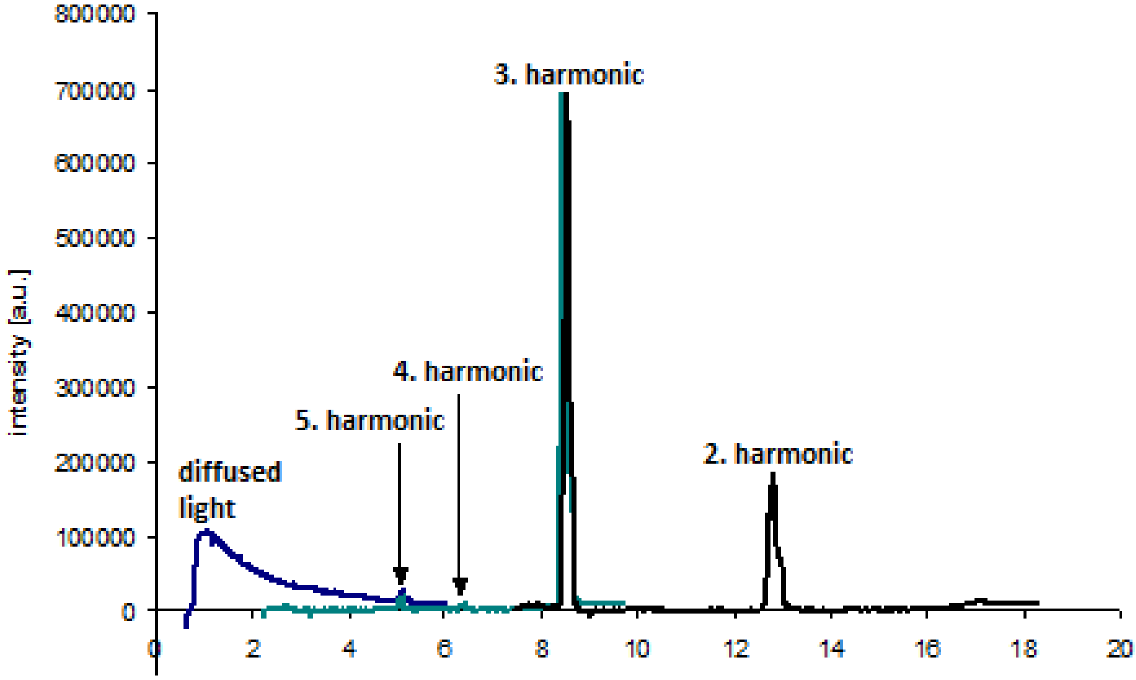


Fig. 6. The 2400 grating

Fig. 6 shows clearly the second and third harmonics. Also the fourth and fifth harmonics are noticeable, but they are merged with the diffusion peak originating from the grating roughness.

The analysis performed provides information about the harmonic components of the beam and their intensities. This information can be used in analysing the measurement data obtained from samples so that the presence of individual components of the beam can be taken into account.

3. References

1. F. Frassetto, S. Coraggia, L. Poletto, N. Guerassimova, S. Dziarzhytski, , E. Ploenjes, H.Weigelt “Compact spectrometer for the analysis of high-harmonics content of extreme-ultraviolet free-electron-laser radiation”
2. K. Tiedtke et al, “The soft X-ray free-electron laser FLASH at DESY: beamlines, diagnostics, and end stations”, New J. Phys. 11, 023029 (2009)