COMMISSIONING RESULTS OF THE PHOTON-ELECTRON DIAGNOSTIC UNIT AT sFLASH*

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Abstract

Recently a test set-up for a seeded free-electron laser operating in the extreme ultra-violet (XUV) spectral range was installed and commissioned at the free-electron laser FLASH. The seed beam is generated by higher harmonics of near infrared laser pulses. A dedicated transport system guides the radiation into the electron accelerator environment. Within the seed undulator section compact diagnostic units were installed to control the transverse overlap of the photon and the electron beam. These units contain a BPM, horizontal and vertical wire scanners and an OTR screen for the electron diagnostic. A Ce:YAG screen and a MCP readout for the wire scanner are used to measure the photon beam position. This paper presents the commissioning results and the performance of the injection beamline and the diagnostic units.

INTRODUCTION

The free-electron laser in Hamburg (FLASH) offers a high brightness photon beam with sub-10 fs pulse length in the extreme ultra-violet (XUV) and soft x-ray regime to various experiments [1]. It operates using the principle of self-amplified spontaneous emission (SASE) where radiation is emitted by a 1.2 GeV high peak current ($\sim$kA) electron beam in a planar undulator. Due to the start up from shot noise this results in a statistical behavior of the emitted FEL spectrum [2]. One possibility to improve the longitudinal coherence of the FEL is to seed the FEL process with external laser radiation and use the FEL as an amplifier. At the same time the temporal stability for pump-probe experiments can be improved, since the laser pulses seeding the FEL and acting as the pump-laser for the experiment originate from the same source. A directly seeded FEL configuration was installed at FLASH in winter 2009. A 40 m long section upstream the existing SASE undulator was rebuild for that purpose [3]. The XUV seed radiation is created by higher-harmonic generation (HHG) from near-infra-red femtosecond laser pulses focused in a noble gas jet. This radiation is guided through a 15 m long differentially pumped transfer line from a laser laboratory into the adjacent accelerator tunnel and into the electron beam pipe. This transfer line includes two motorized mirror chambers to steer the laser beam and thus to control the spatial overlap between the electron and the photon beam. In order to obtain the overlap, diagnostic units are installed at either end of each undulator module. A view of the 3D-model of the diagnostic unit components is shown in Fig. 1. Figure 2 shows a schematic drawing of the injection beamline and the undulator section.

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INJECTION BEAMLINE

The XUV seed beam enters the accelerator tunnel perpendicular to and about two meters below the electron beam axis. A first mirror (*PM8HHGBL*) reflects the beam upwards, where it hits a focusing mirror (*SM12HHGBL*) close to normal incidence. From here, three mirrors (*PM12HHGBL1-3*) bend the beam by a total angle of 84°, so it is aligned collinear with the electron beam. The pitch and yaw angle of the mirror *PM8HHGBL* as well as the transverse position and the angle of the focusing mirror can be remotely adjusted. With that, it is possible to control position and angle of the seed beam at the undulator position. The dynamical angle tolerances for the motion control is below 2 μrad and the positioning tolerance for the focusing mirror 10 μm. These requirements are given due to the photon-electron overlap tolerances for the seeding process discussed in [5]. The focusing mirror can be remotely exchanged with different focal mirrors (f: 6.25 m; 7 m; 8.5 m). This gives the possibility to focus the XUV beam at different positions along the undulator.

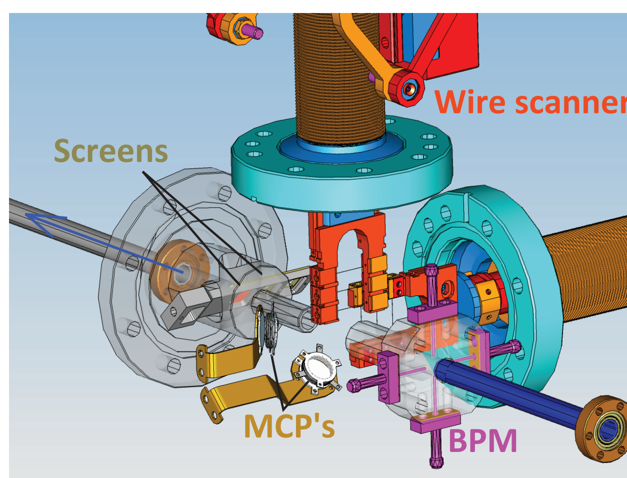

Figure 1: The diagnostic unit to measure the transverse properties of the electron and the photon beam consists of a beam position monitor (BPM), a vertical and a horizontal wire scanner, an aluminum coated silicon screen and a cerium-doped YAG screen [4]. Two micro-channel plates (MCP) close to the wires are used to measure photoelectrons emitted from the wire after the XUV laser interacts with it. The blue arrow indicates the beam direction.

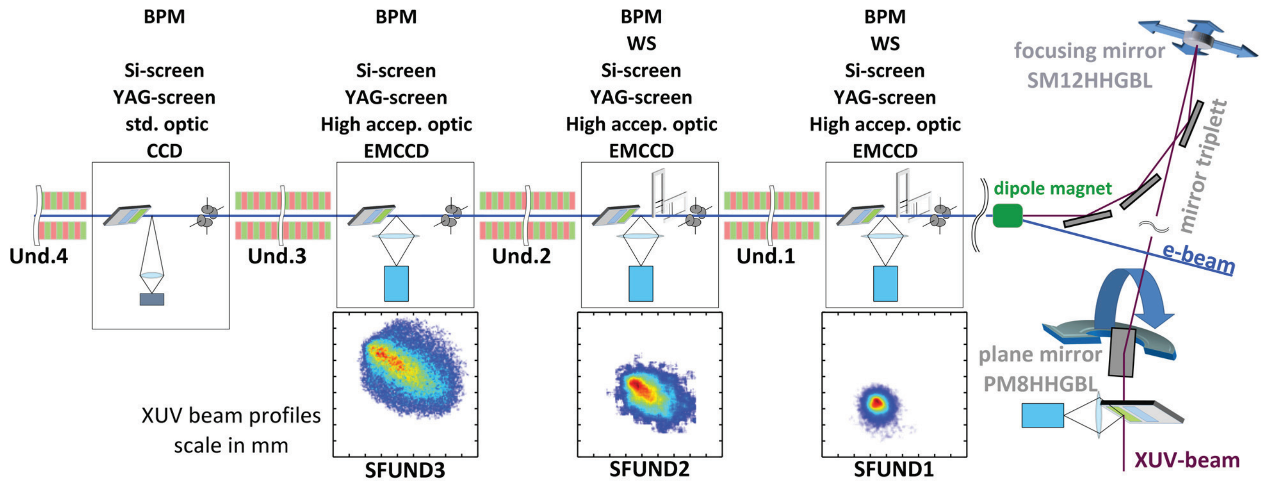

Figure 2: The schematic of the sFLASH beamline, it illustrates the injection beamline for the seed laser and the beam diagnostic stations. Exemplary XUV beam profiles along the undulator using a mirror with a focal length of 6.25 m.

Alignment

Precise alignment of the undulator system, the vacuum chambers and diagnostic units were performed by the DESY survey group. This guarantees an absolute positioning accuracy better that 0.25 mm for each component within the sFLASH section. A laser beam based alignment from the HHG source point to the sFLASH undulator and into the FEL diagnostic branch was performed afterwards. With that, a precise alignment of the mirror chambers was done to set the nominal mirror angles within the required tolerances mentioned above. Finally the laser beam position was measured on the screens of the diagnostic units. The diffraction pattern of the 50 μm tungsten wires could be observed on the screen which gives an absolute position calibration for the screen measurement.

MEASUREMENTS

Transverse Overlap

Beside the spectral and the temporal overlap one of the key challenges for seeding is to achieve the transverse overlap with an adequate coupling efficiency. During the commissioning of the experiment this was done by steering the XUV beam to the electron beam orbit. The latter was set initially to the nominal orbit defined by the wire scanner center positions. Afterwards, it was slightly changed in order to optimize the SASE signal from the sFLASH undulator. The XUV beam was steered using the two motorized mirrors in the injection beamline. Figure 3 shows the electron- and the XUV beam profiles measured with the screens and the wire scanners after adjusting the transverse overlap. Both beams were aligned within 50μrad and 50μm in angle and position. The measurements with the screen and the wire scanners were done consecutively except for the measurement of the XUV beam in the second diagnostic unit (*SFUND2*), seen in Fig. 3(d). The wire scan was performed a few hours after the screen measurements were done. A change of the beam size and the beam position is visible. A possible explanation could be a drift of the HHG drive laser or a change in the HHG parameter.

Beam Sizes

For an effective seeding process the seed beam power should exceed the shot noise power of the electron beam. On the one hand, the XUV beam has to be focused in the beginning of the first undulator module matching the beam size of the electron beam. On the other hand, the field of depth of the focus or in other terms the Rayleigh length of the XUV beam should not be much smaller than the gain length of the FEL. For this reason the XUV beam sizes were measured along the undulator to get an estimate for the waist spot size and position. Figure 2 shows exemplary profiles of the XUV beam measured at three different positions along the undulator for a focal length of 6.25 m. One sees that the beam has an elliptic shape with the semi axis being tilted, which is also observed for the 7 m focal length. The beam shape can be explained by the beam shape of the HHG drive laser which also shows an elliptical shape. The tilt has two reasons: First, the beamline geometry tilts the coordinate system from the HHG source to the undulator by 11.2° clockwise in beam direction. Second, the drive laser has an initial tilt in the HHG source. In addition the beam has an astigmatism which leads to different focus positions for the vertical and horizontal beam axis. Figure 4 shows the results of beam profile measurements using two different focusing mirrors. In the case of the short focal length the foci of the XUV beam are within the first undulator module at z = 28 m. The beam parameters were estimated by fitting the data using a Gaussian beam propagation model. The beam waist sizes within the undulator are w_0^x = 0.693 mm in the horizontal and w_0^y = 0.427 mm in the vertical plane for f = 6.25 m. The Rayleigh length could be estimated to z_R^x = 1.72 m and z_R^y = 0.48 m. The

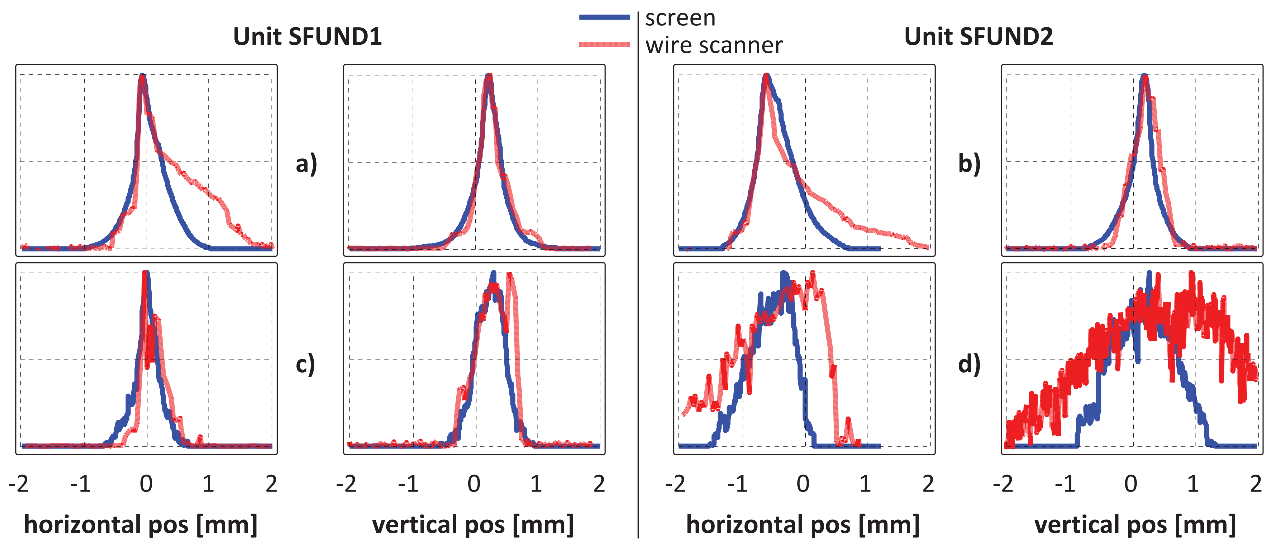

Figure 3: Electron beam profiles (upper row a) and b)) and XUV laser beam profiles (lower row c) and d)) each measured with cerium-doped YAG screens and EMCCD cameras (blue lines) and with wire scanners (red lines) after adjusting the transverse laser position. The profile intensity is normalized for each measurement.

coefficient of determination R^2 is better than 0.996 for each fit.

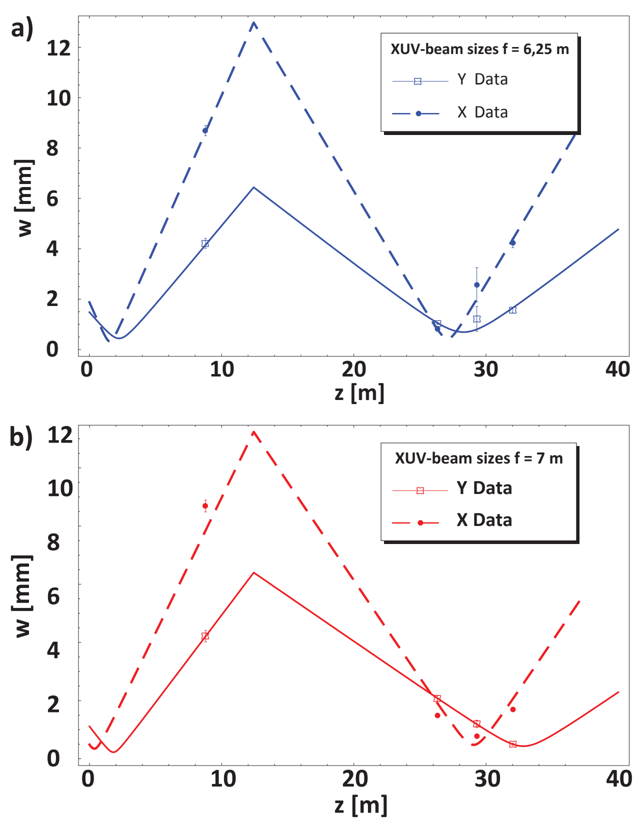

Figure 4: Results of beam size measurements of the XUV beam along the sFLASH injection beamline for different focal length. The dashed and solid lines are fits to the data points using a Gaussian beam transport model. With that, the XUV beam parameter in the undulator can be estimated.

SUMMARY

The injection beamline and diagnostics for the XUV seed laser beam of the seeding experiment at FLASH was successfully commissioned and used to adjust the transverse overlap of the electron and photon beam along the undulator within the required tolerances. Measurements of the XUV beam size show that the seed beam can be focused within the first undulator module.

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