A COMPACT ELECTRON PHOTON DIAGNOSTIC UNIT FOR A SEEDED FEL*

J. Bödewadt†, J. Roßbach, University of Hamburg, Germany
B. Polzin, H. Schlarb, A. de Zubiaurre Wagner, DESY, Hamburg, Germany
R. Ischebeck, PSI, Villigen, Switzerland

Abstract

A seeded free-electron laser (FEL) operating in the soft X-ray (XUV) spectral range will be added to the SASE FEL facility FLASH. The seed beam will be generated by higher harmonics of a near infrared laser system. A dedicated transport system will guide the radiation into the electron accelerator environment. Within the seed undulator section compact diagnostic units have to be designed to control the transverse overlap of the photon and the electron beam. These units contain a BPM a wire scanner and an OTR screen for the electron diagnostic. A Ce:YAG screen and a MCP readout for the wire scanner are foreseen to measure the photon beam position.

INTRODUCTION

The free-electron laser in Hamburg (FLASH) offers high brightness photon beam with sub-10 fs pulse length in the vacuum ultra-violet (VUV) and soft x-ray (XUV) regime to various experiments [1] . It operates using the principle of self-amplified spontaneous emission (SASE) where radiation is emitted by a 1 GeV high peak current (∼kA) electron beam in a planar undulator. Due to the start up from shot noise this results in a statistical behavior of the emitted spectrum [2]. Beside that the arrival-time jitter of the FEL pulses is in the order of a few 100 fs which limits the temporal resolution for pump-probe experiments [3] where an external laser system has to be synchronized with the accelerator. One way to reduce this time jitter is to seed the FEL process with an external laser and combine the amplified radiation pulse with near infra-red pulses from the same laser system. Since the two radiation pulses originate from the same source they are intrinsically synchronized. A directly seeded FEL configuration is going to be installed at FLASH in winter 2009 [4]. A 40 m long section upstream the existing SASE undulator will be rebuild for that purpose. Figure 1 shows a general layout of that section. The XUV seed radiation is created by higher-harmonic generation (HHG) from NIR femtosecond laser pulses focused in a rare gas jet and 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 beam and thus to control the spatial overlap between the electron and the photon beam. In order to obtain the overlap, diagnostic units will be installed at either end of each undulator module. Each unit accommodate an electron beam position monitor (BPM), vertically and horizontally installed wire scanners (WS), an aluminum coated silicon screen for optical transition radiation (OTR) measurements and a Ce:YAG crystal.

* Funded by the Federal Ministry of Education and Research of Germany under contract 05 ES7GU1
† contact: joern.boedewadt@desy.de

SPATIAL OVERLAP

One of the key challenges of the seeding experiment is to achieve the spectral, temporal and spatial overlap. The latter will be obtained by either steering the electron beam onto the photon beam or vice versa. Therefor two pairs of dipole corrector magnets (horizontal and vertical) preceding the sFLASH undulator and two motorized mirrors inside the XUV-seed transfer line will be installed. Each of the mirrors can be steered in two dimensions thus the

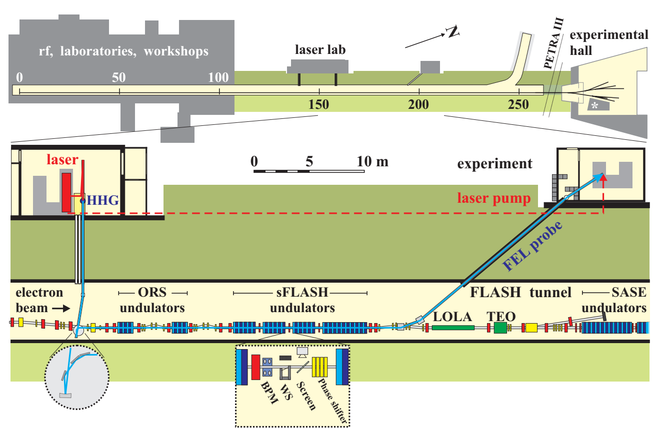

Figure 1: The FLASH facility (top) comprises a 260 m long tunnel housing the linac and undulators of a SASE FEL, followed by an experimental hall. A 40 m long section (bottom) will be rebuilt to accommodate four additional undulators for sFLASH. Seed pulses from an HHG-source in a building adjacent to the FLASH tunnel will be aligned to the electron beam. At the undulator exit, the FEL radiation is sent by mirrors to an experimental hutch. Delayed laser pulses will be sent directly to the hutch for pump-probe applications (dashed line).

position and angle adjustment of the photon beam within the undulator is possible. During the commissioning of the experiment the spatial overlap will be the second of the three step to assure a six-dimensional overlap. After setting the variable-gap undulators to fulfill the resonant condition with respect to the electron beam energy and the seed wavelength, the transverse positions of the seed and the electron beam have to be matched. This will be done by measuring and aligning the two beams at the entrance and the exit of the first undulator module using the OTR and the Ce:YAG screen. The last step to establish seeding is to set the right timing between the two femtosecond pulses to achieve temporal (longitudinal) overlap which will be another challenge [5].

Tolerances

Numerical simulations were performed to estimate the tolerances for the electron beam transverse offset and angle with respect to photon beam [6]. Assuming a tolerance for the radiation power of the seeded FEL of 5% the simulation shows a maximum accaptable offset of 35 μm and a maximum angle of 20 μrad for the two beam with respect to each other. Based on that numbers the position and angle adjustment tolerances for the photon beam were set to 10 μm and 5 μrad respectively.

DIAGNOSTIC UNIT

The sFLASH undulator has three 0.7 m long intersections were a quadrupole, a phase shifter, a dipole corrector coil and a beam diagnostic unit has to be installed. Figure 2 shows a technical drawing of one of these sections. A fourth diagnostic unit will be installed at the entrance of the undulator. The maximum space available for the design is 20 cm. All units will be equipped with a carrier on a linear translation stage to mount a silicon screen, a Ce:YAG crystal and a calibration screen. Together with an appropriate optical system and a CCD camera ,this gives the possibility to measure beam size and position for electron and photon beams on a single shot bases. Furthermore button type beam position monitors (BPM) on the undulator intersection units and a strip line BPM at the undulator entrance will be installed [7]. In addition the first two units accommodates a horizontally and a vertically installed wire scanner with two multichannel plates to detect scattered photons and electrons respectively. Scintillator panels mounted beside the undulator will give the possibility to detect electron showers produced by the wire scanners.

Wire Scanner

The wire scanners were designed and built for a self-seeding option at FLASH [8] and are of the same type as used in the SASE undulator section at FLASH [9]. For sFLASH they will be equipped with a tungsten wire of 15 μm diameter and two carbon wires with 10 μm and 5 μm diameter.

Imaging System

For precise emittance measurement using the four screen method the electron beam size has to be measured with an error better than 10% of the rms beam size. Therefore the imaging system of the diagnostic units has to garantee a resolution of 10 μm/pixel with a design electron beam size of 100 μm. The standard camera system [10] installed at FLASH uses cameras with a pixel size of 9,9 μm [11]. The third and fourth diagnostic unit will operate with these camera types too. A simple 1:1 imaging setup can be used at that positions. For the first and second unit the signal-to-noise ratio of the standard system won't be sufficient to diagnose the XUV photon beam on the Ce:YAG crystal even with a large aperture lens. Therefor a more sensitive EM-CCD camera system will be used with a telescope like lens system (see Fig. 3). To avoid image destortions an aspherical lens with a focal length of 80 mm and an diameter of 45 mm is installed right after the vacuum window resulting in an acceptance angle of 30°. Another lens system with a focal length of 75 mm will image the screen on the CCD resulting in a magnification of 0,94. With a camera pixel size of 8 μm the resolution is good enough for precise emittance mesurements and to diagnose the XUV seed beam. Differ-

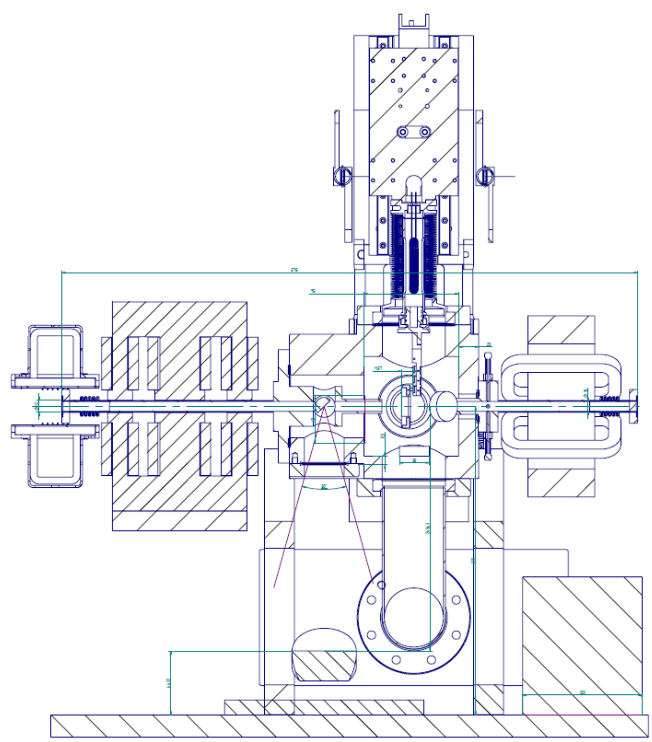

Figure 2: A sectional drawing of the sFLASH undulator intersection. Components from left to right: dipole corrector coil, phase shifter, diagnostic unit, quadrupole. The diagnostic unit accommodate a button BPM (right), wire scanners (vertical type on top), MCP for photon/electron detection and a carrier (left) with a silicon screen and a Ce:YAG crystal. The diameter of the vacuum chamber is 10 mm.

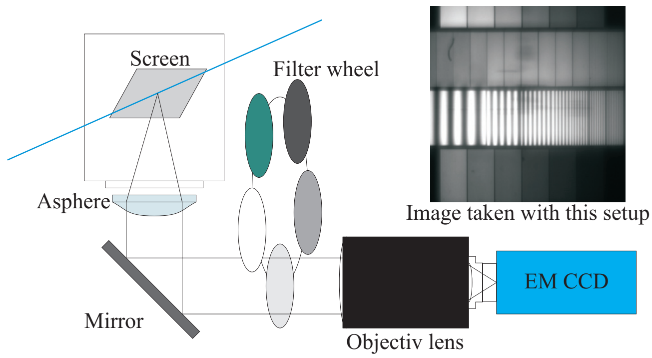

Figure 3: Layout of the imaging system for the OTR/Ce:YAG diagnostics. From the screen emitted radiation is collimated with an aspherical lens ($f = 80\,\text{mm}$) and focused by a commercial lens ($f = 75\,\text{mm}$). A motorized filter wheel allows five different attenuation factors. The small image shows a sine test pattern imaged with this setup.

ent color and grey filters will be installed on a motorized filter wheel to avoid saturation of the CCD and to protect it against high intensity laser beams.

SUMMARY

In order to commission and control the spatial overlap between an XUV photon beam and the electron beam for a direct seeding experiment at FLASH compact diagnostic units were designed. Combining standard beam position monitoring instruments for both electron and photon beams it will work as an essential tool during the first phase of the seeding experiment.

ACKNOWLEDGMENTS

Special thanks to people from different groups at DESY (among them FEB, FH1, MCS, MVS, ZM and Zeuthen). Their support is gratefully acknowledged. The project is supported by the Federal Ministry of Education and Research of Germany under contract 05 ES7GU1.

REFERENCES

[1] W. Ackermann et al., *Operation of a free-electron laser from the extreme ultraviolet to the water window*, Nature Photonics 1 (2007), p. 336.

[2] E. L. Saldin et al., *The Physics of Free Electron Lasers*, Springer Berlin (1999).

[3] A. Azima et al., *Jitter Reduced Pump-Probe Experiments*, Proceedings of DIPAC'07, Venice, (WEPC13).

[4] S. Khan et al., *sFLASH: An Experiment For Seeding VUV Radiation at FLASH*, Proceedings of FEL'08, Gyeongju, (TUPPH072).

[5] R. Tarkeshian et al., *Conceptional Ideas For The Temporal Overlap Of The Electron Beam And The Seed Laser For sFLASH*, Proceedings of FEL'08, Gyeongju, (TUPPH051).

[6] V. Miltchev et al., *Tolerance Studies On The High Harmonic Laser Seeding At FLASH*, Proceedings of FEL'08, Gyeongju, (TUPPH003).

[7] N. Baboi et al., *Beam Position Monitor Calibration at the FLASH Linac at DESY*, Proceedings of PAC'07, Albuquerque, (FRPMN017).

[8] J. Feldhaus et al., *Possible application of X-ray optical elements for reducing the spectral bandwidth of an X-ray SASE FEL*, Opt. Commun., 140 (1997), p. 341.

[9] U. Hahn et al., *Wire scanner system for FLASH at DESY*, Nuc. Inst. Methods **A 592** (2008), p. 189.

[10] G. Grygiel et al., *DOOCS Camera System*, Proceedings of ICALEPCS'07, Knoxville, (WPPA21).

[11] Basler AG, A300-Serie, `http://www.baslerweb.com`