PAPER • **OPEN ACCESS**

A Laser Heater Undulator for FLASH2020+

To cite this article: S Telawane *et al* 2022 *J. Phys.: Conf. Ser.* **2380** 012028

A Laser Heater Undulator for FLASH2020+

S Telawane, A Schöps, P Neumann, T Ramm, M Tischer and P Vagin

Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

E-mail: `pavel.vagin@desy.de`

Abstract. Space charge induced micro bunch instabilities, amplified in cascaded bunch compression stages, spoil the phase space of compressed bunches and lead to unstable seeding. To "heat" up the bunch with an external laser and induce an uncorrelated energy spread to suppresses the micro bunching instabilities, a short undulator will be installed in front of the first compression chicane. The undulator has a planar hybrid magnet structure with 43 mm period length, 11 full periods, 22 mm minimum gap and a deflection parameter K of 1.52 (K = (eBλ_u) / (2πm_ec), with B - max. magnetic field amplitude, λ_u - period length) to match the 534 nm laser wavelength at 146 MeV beam energy. The paper describes the undulator's compact design, its control system and results of magnetic measurements and tuning.

1. Introduction

A laser heater will be implemented in the 1st bunch compressor of the FLASH linac as part of the upgrade program FLASH2020+ [1]. Similar systems are in operation at other facilities [2, 3] for the suppression of micro bunching which may degrade the seeding process. The FLASH laser heater undulator (LHU) will be located upstream of the first bunch compressor chicane (FL0CBC1). Figure 1 shows the overview of the undulator setup in the tunnel.

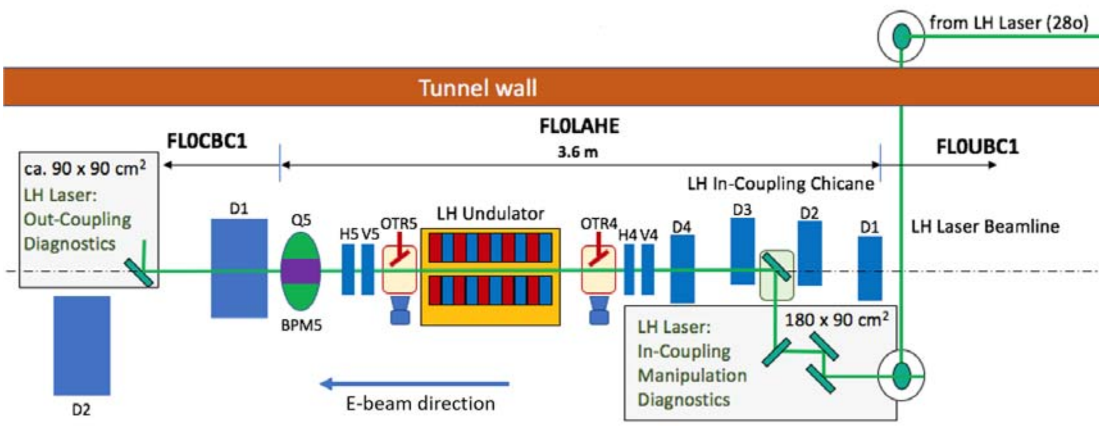

Figure 1: FLASH2020+ laser heater setup.

The laser heater setup consists of an in-coupling (D1-D4) and an out-coupling chicane (part of FL0CBC1) for the laser beam which is superimposed with the electron beam inside the LHU. A set of vertical and horizontal steerers is used for matching and OTR (Optical Transition Radiator) screens on both sides serve for diagnostics. An optical laser will be overlaid with the electron beam (nom. beam energy 146 MeV) in the LHU to induce an energy modulation on the scale of the laser wavelength. The energy-position correlation is smeared out in the bunch compressor chicane causing the electron beam heating.

2. Compact Design

One of the main challenges involved in designing the unit was to make it compact to fit in the installation space of max. 566 mm in beam direction. The magnetic arrays including the end poles and the magic fingers have to be accommodated within this space. Figure 2 shows a 3D model of the LHU together with a side and front view.

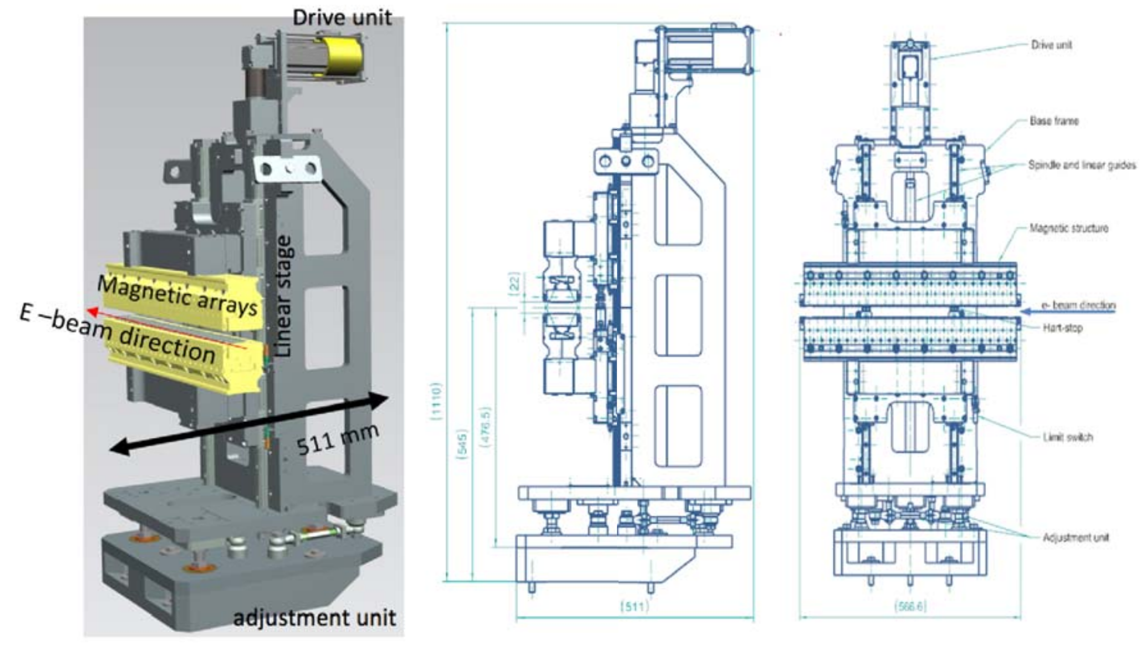

Figure 2: 3D model, side and front view of the LHU setup with its sub-systems.

The overall height of the device is determined by several aspects. One of the aspects is the linear drivetrain for opening and closing the magnetic gap. The minimum working gap of 22 mm is defined by the aperture required for the electron beam in order to keep losses on a tolerable level. Necessary space for measurement tools for magnetic tuning together with the required components of the drivetrain result in a total height of about 700 mm allowing for a gap range from 22 mm to 220 mm. For compactness, the gearbox and motor at the top end are placed in a 90°-tilted configuration. An adjustment base

Journal of Physics: Conference Series **2380** (2022) 012028 doi:10.1088/1742-6596/2380/1/012028

is placed underneath the actual gap mechanics. This allows for a vertical adjustment of ±11 mm and a horizontal adjustment in all directions of ±15 mm for final alignment of the undulator with respect to the beam axis.

3. Control System

The characteristics of the drive system are listed in table 1. The main component of the control system is a compact synchronous servomotor equipped with an 18 bit multiturn absolute rotary encoder and built-in holding brakes. It drives the main spindle with a left-hand and a right-hand thread and a diameter of 25 mm. The EtherCAT box used as a servo drive for the motor helps to set the motor parameters directly in the TwinCAT system and simplifies the configuration. The control system is based on a software-NC (Numerical control) and -PLC (Programmable logic controller) running on a compact PC with a Windows 10 IoT operating system. It handles the positioning of the girders and safety-features like limit-switches.

Table 1: Control system characteristics

Electrical and Mechanical data	Values
Motor power @24 V	50 W
Rated torque	0.8 Nm
Rated speed @24 V	600 rpm
Gearbox ratio	i = 1 : 32
Gearbox efficiency	91%
Spindle pitch	5 mm(1/r)
Typical gap movement	up to 2 * 1.22 mm/s

The control system provides a user-interface for commissioning as well as an interface to the global FLASH control system. The development environment used for the laser heater is TwinCAT 3. Using TwinCAT 3 for the laser heater undulator will serve as a test case for the series of future seeding undulators and phase shifters at FLASH2020+ where TwinCAT 3 shall be implemented throughout. This will allow for replacing outdated software components from older FLASH undulator control systems based on TwinCAT 2.

4. Magnetic Design and Measurements

The undulator has a hybrid magnetic structure with a period length of 43 mm which matches the spectral requirements for the specified minimum gap of 22 mm. The LHU is designed for a laser wavelength of 534 nm with the possibility of tuning the wavelength by at least 5% for commissioning purposes (figure 3). The cross-section of poles and magnets has been adapted from the FLASH2 undulators [4]. This allowed for a simple mechanical adaption of the compact magnet structure.

Sm_2Co_{17} magnet material (262HR with 1.15T remanence, 23kOe coercivity) was selected for its increased radiation hardness. Poles are from VACOFLUX 50. Because the length of magnetic structure is limited to 11 periods only, it was decided not to sacrifice two full periods for a conventional "+1/4, −3/4, +1" end structure. Instead only single reduced end magnets are used. This results in a larger trajectory excursion on the first pole, but size and vertical position of the end magnet was optimized to have minimal kick and trajectory offset for different gaps (figures 4 and 5). Field maps, to calculate the trajectory and dynamic multipoles, were measured using 3D Hall probe bench, field integrals with a stretched wire.

Table 2: Laser heater parameters

Nominal beam energy	146 MeV
Laser wavelength	534 nm (2.32 eV)
Minimum gap	22 mm
Period length	43 mm
Max. K parameter	1.52
Magnet material	SmCo
Number of periods	11
Undulator length	0.473 m
Maximum beam excursion	±35 μm

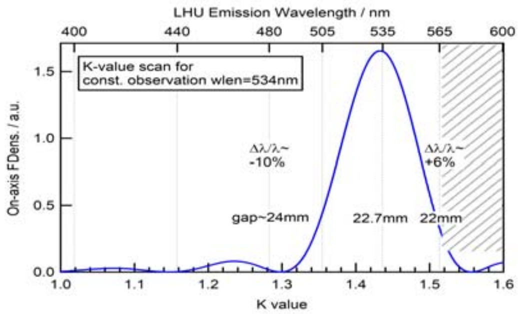

Figure 3: Spectral flux density vs K.

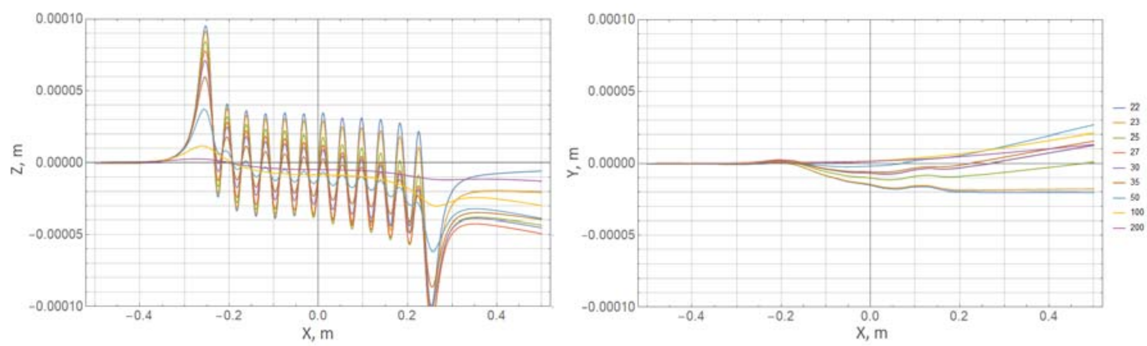

Figure 4: Horizontal (left) and vertical (right) trajectory gap dependence after tuning, residual gap dependent kicks are within ±40 μrad.

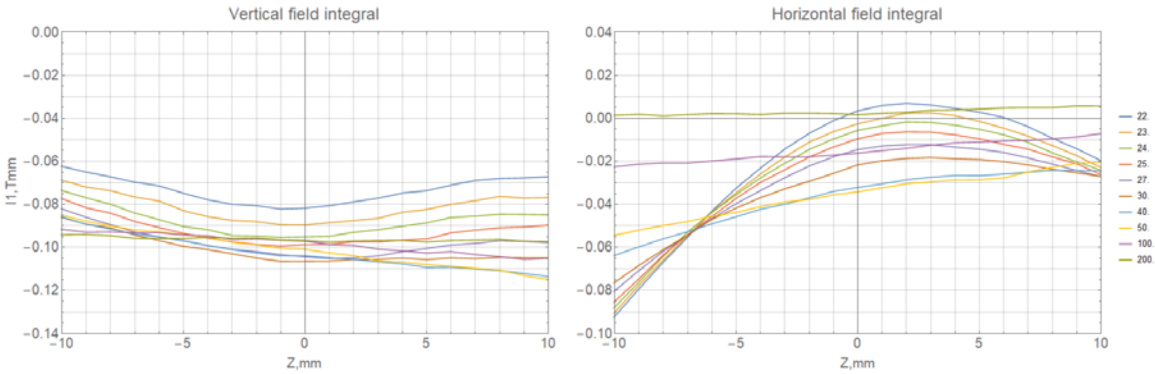

Figure 5: Transverse dependence of field integrals for different gaps after tuning. The residual gap dependent kicks are within $\pm 20\,m$Tmm, corresponding to $\pm 40\,\mu$rad.

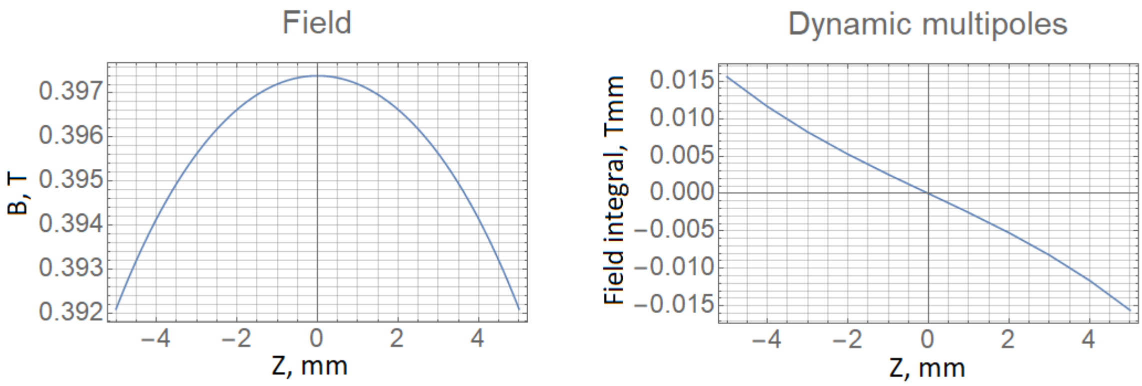

Figure 6: Transverse field roll-off dependence and corresponding dynamic multipoles.

At the low beam energy of 146 MeV, a large electron trajectory excursion in a non-uniform field (transverse field roll-off on figure 6) results in additional defocusing [5]. Transverse electron displacement, when following a sinusoidal trajectory in a transverse field gradient, results in "positive" and "negative" trajectory halfperiods, which are not in the same field amplitude. This induces small additional kicks every period, away from the center, which affects the electrons like an additional defocusing quadrupole field.

However, for this short structure with a not very long period length, the dynamic multipoles are comparable to the remaining static magnetic multipole errors (figure 5) and are within the specification.

5. Conclusion

A compact laser heater undulator has been designed and constructed as part of the first upgrade phase within the FLASH2020+ project. A simplified field termination of the magnet structure has been implemented in order to maximize the number of available full periods within the restricted given length. SmCo permanent magnet material has been applied for the sake of better radiation resistivity as the undulator is installed in the upstream section of the accelerator near the bunch compressor where higher beam losses are usually expected. All remaining field errors are close to negligible and can easily be corrected by steerers next to the undulator. The LHU is presently being installed in the machine and commissioning with beam is expected later this year. Experience will be gained with the control system which has been upgraded towards TwinCAT 3 in view of the new undulators to come in the 2nd phase of the project.

6. References

[1] Gerth C., Allaria E., Choudhuri A., Schaper L., Schneidmiller E., Schreiber S., Tischer M., Vagin P., Vogt M., Winkelmann L. and Yurkov M.V., 2021, May. Layout of the Laser Heater for FLASH2020+. In *Proceedings of the 12th International Particle Accelerator Conference, Campinas, Brazil* (pp. 24-28).

[2] Huang Z., Brachmann A., Decker F.J., Ding Y., Dowell D., Emma P., Frisch J., Gilevich S., Hays G., Hering P. and Iverson R., 2010. Measurements of the linac coherent light source laser heater and its impact on the x-ray free-electron laser performance. *Physical Review Special Topics-Accelerators and Beams, 13*(2), p. 020703.

[3] Spampinati S., Allaria E., Badano L., Bassanese S., Biedron S., Castronovo D., Craievich P., Danailov M.B., Demidovich A., De Ninno G. and Di Mitri S., 2014. Laser heater commissioning at an externally seeded free-electron laser. *Physical Review Special Topics-Accelerators and Beams, 17*(12), p. 120705.

[4] Bilani O., Neumann P., Schöps A., Tripathi S., Vagin P., Vielitz T. and Tischer M., 2014. Magnetic tuning of Flash2 undulators. *Proc. IPAC,* pp. 1235-1237.

[5] Vagin P., Bilani O., Schöps A., Tripathi S., Vielitz T. and Tischer M., 2014. Radiation damage of undulators at PETRA III. *Proceedings of IPAC2014, Dresden, Germany,* pp. 2019-2021.