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REDESIGN OF THE FLASH2 POST-SASE UNDULATOR BEAMLINE

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Abstract

FLASH2 is one of the two SASE (Self-Amplified Spontaneous Emission) undulator beamlines lines comprising variable gap undulators to produce radiation in the XUV and soft X-ray regime at FLASH. Downstream of the SASE undulators the beamline is currently undergoing a major redesign. During shutdowns in summer 2020 and winter 2021 two PolariX TDSs (Polarizable X-band Transverse Deflecting Structure) were installed, as well as additional diagnostics, to monitor the longitudinal phase space density of the electron bunches. Additionally, an afterburner undulator will be integrated in the next shutdown to produce circularly polarized light with wavelengths down to 1.39 nm. In this paper, we will present the modifications that were and will be made to the electron beamline in the course of this redesign.

INTRODUCTION

The FLASH facility is currently undergoing a major refurbishment as part of the FLASH2020+-project [1]. During the first upgrade phase, a redesign of the FLASH2 post-SASE (Self-Amplified Spontaneous Emission) undulator beamline is realized. This includes the integration of two PolariX TDSs (Polarizable X-band Transverse Deflecting Structure)) [2, 3] and an afterburner undulator.

The PolariX TDS was developped in a collaboration between CERN, PSI, and DESY. The key feature of this TDS is the possiblity to set the direction of the streaking field to arbitrary angles, thus providing a transverse streak in any direction. The PolariX TDS at FLASH2 complements the TDS installed at FLASH1 [4] in providing a reliable method to monitor the electron bunch length as well as their longitudinal phase space density (LPSD). At DESY, two more facilities are or will be equipped with PolariX TDSs. The FLASHForward facility received the PolariX TDS prototype, where the initial commissioning and testing took place [2, 3, 5] and also the SINBAD facility will receive two structures [6, 7].

PolariX TDSs FOR FLASH2

The key ingredient of the lasing process in a free-electron laser (FEL) are the longitudinal parameters of the electron bunches. To control and monitor the lasing process the measurement of the longitudinal properties of the electron bunches is of utmost importance. For this purpose, two PolariX TDSs were installed at FLASH2. With these devices it is possible to relate the longitudinal coordinate of an electron beam to a transverse one which then can be imaged using a screen. Additionally, an energy spectrometer, such as a dipole magnet, deflecting the beam in the plane transverse to the streaking plane of the TDS can be used to relate the beam energy to the other transverse coordinate. By combining both methods, the LPSD of the electron bunches can be mapped onto a screen [8]. With the variable polarization feature of the PolariX TDS, it is also possible to perform slice emittance measurements in both transverse planes and to perform a 3D charge tomography of the electron beam [3, 9, 10].

Beamline Redesign and Installation

To integrate the PolariX TDSs downstream of the FLASH2 undulators, significant changes had to be done to the beamline. Not only the two PolariX TDSs were installed, but also two new quadrupoles, a beam kicker, and a new screen station. One of the new quadrupoles is the first quadrupole at FLASH, which not only houses the electron beamline inside of the yoke but also the photon beamline, see Fig. 1. The quadrupole is situated very close to the separation dipole for the photons and the electrons, therefore the beamlines are still very close to one another. It is needed for optimal focussing of the beam onto the screen used for LPSD measurements. The beamline redesign is described in detail in [11].

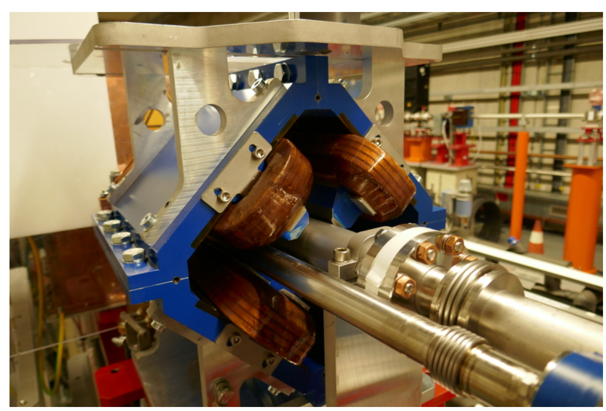

Figure 1: Quadrupole downstream of the separation of the photon and the electron beamline. The photon beamline is inside of the iron yoke of the magnet.

Regarding the RF (radiofrequency) input for the PolariX TDSs, the peak power available from the 6 MW klystron can now be quadrupled using and X-band barrel open cavity (XBOC) [2, 12] pulse compressor. this device was installed in the waveguide distribution in the latest shutdown. Figure 2 shows an image of the XBOC.

The installation of the components was carried out over the summer shutdown in 2020 and the winter shutdown in

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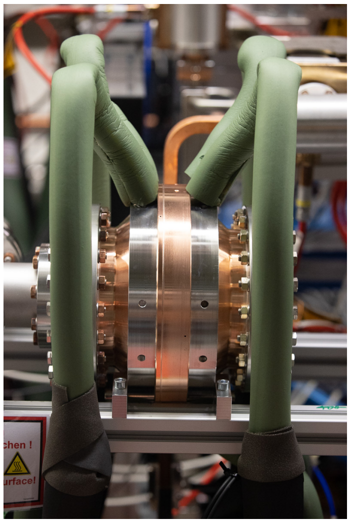

Figure 2: X-band barrel open pulse compressor (XBOC) used to quadruple the power coming from the klystron. Image courtesy of D. Nölle.

2020/2021. An image of the installed structures is shown in Fig. 3.

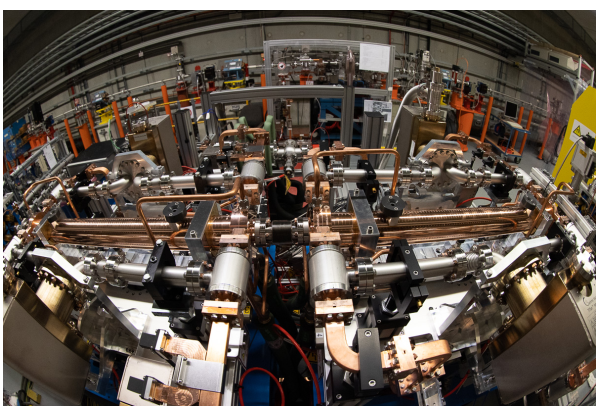

Figure 3: Top view of the two newly installed PolariX TDSs. The beam direction is from right to left, the last FLASH2 SASE undulator is visible on the right hand side (yellow girder). Image courtesy of D. Nölle.

Conditioning and Commissioning with Beam

The RF structures have not been pre-conditioned. We started the conditioning process slowly without the XBOC. We increased the RF power step by step and achieved up to now stable operation with 3 MW allowing first measurements using PolariX.

The first commissioning with beam was also done recently. For the first time at FLASH2, the LPSD of the electron bunches could be measured directly. Figure 4 shows an image of the LPSD with open undulators. The achieved time resolution in this case was about 10 fs and one can clearly see microbunching effects along the beam.

In the future, the PolariX TDS will be routinely used to set up the machine for users, to monitor the electron bunch

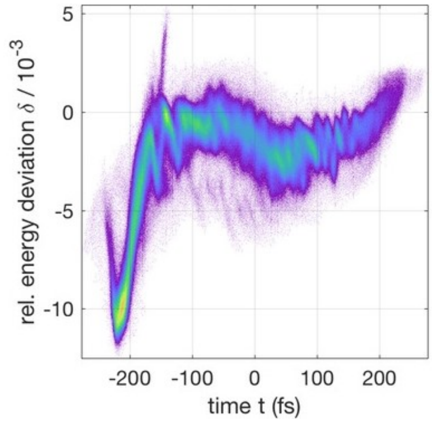

Figure 4: Example of first measurements of the LPSD with the newly installed PolariX at FLASH2. The resolution achieved with an RF input power of 3 MW was 10 fs, which is already impressive.

length and reconstruct the photon pulse duration. Additionally, it can be used as a valuable tool to investigate beam dynamics effects, such as microbunching due to coherent synchrotron radiation or space charge effects [13–15].

AFTERBURNER UNDULATOR FOR FLASH2

For the FLASH2020+ project, an afterburner undulator will be installed downstream of the FLASH2 SASE undulators. This will serve to produce switchable circularly polarized light with a wavelength of 1.39 nm to 1.77 nm (890 eV - 700 eV) to investigate the L-edges of Fe, Co, and Ni. The design is based on an Apple III-type undulator and is developped at DESY. Figure 5 shows an image of the afterburner prototype.

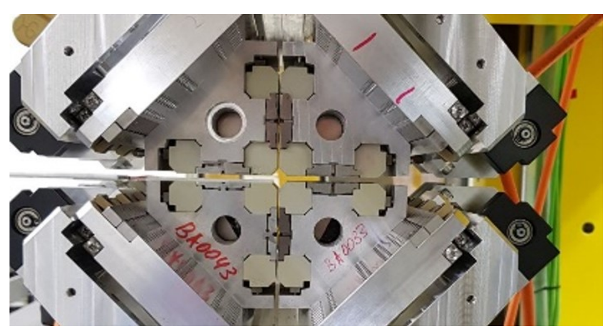

Figure 5: Picture of the APPLE III afterburner prototype. Each of the four quadrants can be moved longitudinally to change the polarization. Image courtesy of M. Tischer.

The integration of this device requires moving the last FL2SASE undulator to the front of the undulator section to generate space. The afterburner undulator will then be situated between the FLASH2 SASE undulators and the PolariX TDSs.

Inbetween the undulators, so-called intersections are installed. They contain for example a quadrupole, a BPM, and

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phase shifters, and were fabricated in a way, that they can in principle be exchanged. Three of the undulator intersections need to be moved and one of those needs to be modified for the integration of the afterburner undulator. The intersection currently installed in front of the FLASH2 SASE undulators will be exchanged with the intersection installed in front of the undulator. This serves to have a phaseshifter between the future first and second undulator and to have a vertical and a horizontal steerer in front of the afterburner undulator to optimize the orbit in this undulator.

Additionally, the new intersection in front of the undulator chain also receives a steerer pair for optimizing the orbit through the undulators. Also, an OTR screen will be installed at this intersection to measure the Twiss parameters in front of the undulators also with the changed configuration. Currently, this was done using a four screen method, but one of the screens has to be removed to make space for the moved SASE undulator.

Multi-Screen Matching in FLASH2 Undulator Section

As a future upgrade option, three additional beam size monitors could be integrated in the FLASH2 undulator section. Currently, unused wirescanner chambers without working wirescanners are installed at three adjacent intersections in the undulator area. To have a good option for matching into the undulator, we propose to add OTR screen stations or wirescanners in some intersections. By distributing them in a way, that every second intersection is equipped with a measurement station, including the one in front of the undulators, one could use a four screen method to measure the Twiss parameters. For this, we propose a lattice with a phase advance in both planes of $\Delta\Phi_{x,y} = 70°$. The optical functions for the new lattice are shown in Fig. 6.

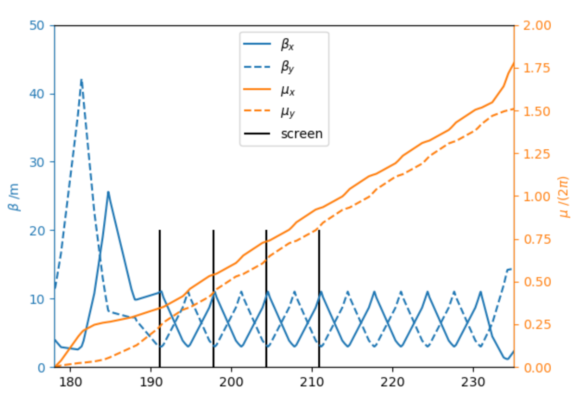

Figure 6: Optical functions proposed for matching into the FLASH2 undulators using a four screen method. The phase advance between the screens is $\Delta\Phi_{x,y} = 70°$.

CONCLUSION

The FLASH2 post-SASE undulator beamline is currently undergoing a major upgrade. After the successful integration of two PolariX TDSs, the next step is to install an afterburner undulator. This device will be used to produce circularly polarized light with a wavelength of down to 1.39 nm for the users.

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