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SASE3 VARIABLE POLARIZATION PROJECT AT THE EUROPEAN XFEL

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Abstract

At the European XFEL, two undulator systems for hard and one for soft X-rays have been successfully put into operation [1]. The SASE3 soft X-ray undulator system generates linearly polarized radiation in the horizontal plane. One of the requirements for extending the radiation characteristics is the ability to obtain different polarization modes. These include both right and left circular, elliptical polarization, or linear polarization at an arbitrary angle. For this purpose, a system consisting of four APPLE X helical undulators developed at the Paul Scherrer Institute (PSI) is used [2, 3]. This paper presents the design parameters of the SASE3 undulator system after modifying it with the helical afterburner. It also describes the methods and the design solutions different from those used at PSI. The status and schedule of the project are introduced.

PROJECT IMPLEMENTATION CONCEPT

The SASE3 undulator system consists of 21 planar U68 variable-gap undulators, each 5 m long with a period of 68 mm. Depending on the energy of the electron beam (8.5 GeV - 17.5 GeV), this system can generate radiation in the range from 0.24 keV to 4.6 keV. The purpose of modifying the SASE3 beamline is to enable the generation of soft X-rays with desired polarization. At European XFEL it was decided to use the method of obtaining a high degree of circular polarization using a reverse undulator tapering [4]. The essence of the idea is to use a micro bunched electron beam after a system of planar undulators and direct it into a system of helical undulators tuned to the resonant frequency, where it will emit powerful coherent radiation with controlled polarization. To achieve a high degree of, for instance, circular polarization, it is necessary to suppress or cut off the linear polarization generated by the planar undulators. Specifically, for this purpose, it is proposed to use the planar undulators in reverse tapering mode. In this mode, the bunching factor is approximately the same as for nontapered undulators, but the radiation power decreases by orders of magnitude.

The results of a numerical 3D simulation using the FAST code [5] show that, for example, at a wavelength of 1.5 nm (0.83 keV), using the last 11 planar undulator cells with a total length of 55 meters, in the 2.1% reverse taper mode, the linearly polarized power reaches a value of 0.4 GW, while the bunching factor increases continuously. The power of circularly polarized radiation generated by a 10 m long helical undulator, located directly behind the system of linear undulators, increases very rapidly and reaches up to 155 GW. Hence, the degree of circular polarization reaches a value of ~99.9%. Similar results were obtained using a numerical three-dimensional SIMPLEX simulation [6]. Table 1 shows the simulation results for four wavelengths considering a helical afterburner of eight- or twelve-meters composition length [7].

Table 1: Radiation Power, Generated by the Helical Afterburner at Circular and Linear Polarization

Photon Energy	**Planar Undulators**	**Helical afterburner length**			
		8 m		12 m	
$\hbar\omega$ [keV]	Quantity	P_{Cir} [GW]	P_{Lin} [GW]	P_{Cir} [GW]	P_{Lin} [GW]
3.10	16	19	10	36	16
1.55	14	55	25	104	40
0.77	12	110	46	168	81
0.25	10	150	80	160	103

Experimental confirmation of the above method was demonstrated at FLASH [8] showing high contrast operation when the afterburner was tuned to the fundamental frequency.

These studies were the basis for calculating the electron beam optics in the installation area of the helical afterburner system.

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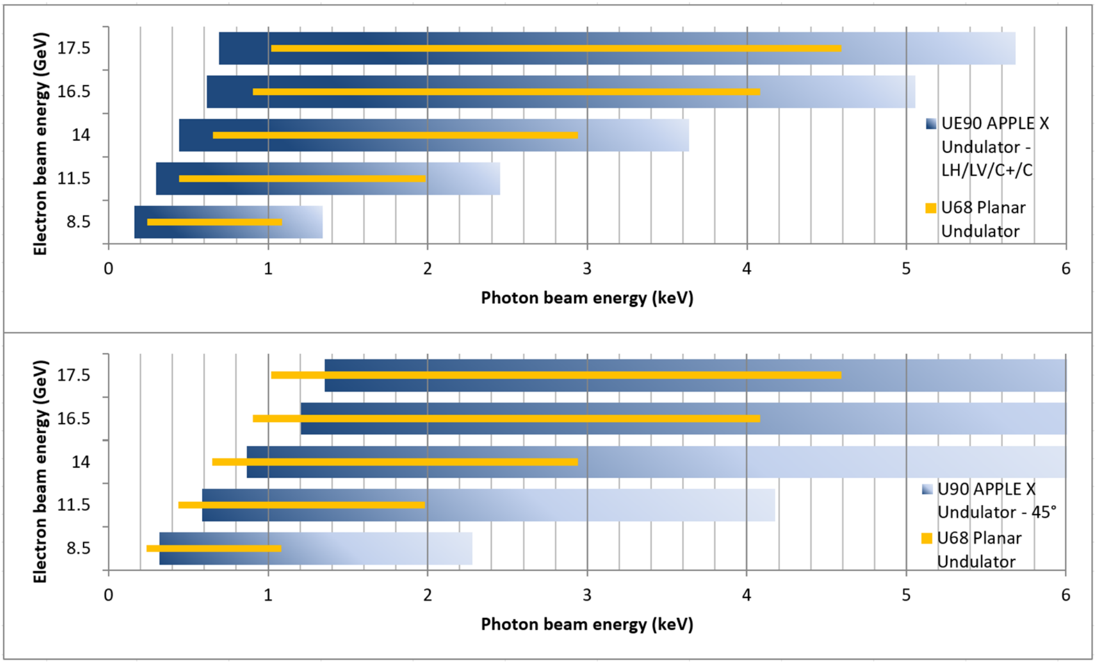

Figure 1: Photon energy ranges generated by helical UE-90 and planar U68 undulators. The upper figure shows the case of vertically and horizontally as well as circularly polarized modes. The lower figure illustrates the case with linear polarization at an angle of 45°.

MODIFICATION OF THE ELECTRON BEAM OPTICS

To create a system of helical undulators for SASE3, a new so-called APPLE X-type of a helical undulator was chosen. The frame length of this undulator is slightly over two meters. It was decided to use the existing design of the intersection and its components. The tunnel infrastructure is prepared to be completed with two more undulators. The results yielded from the calculation of the magnet lattice and optics in the afterburner section are the following: (1) The afterburner section starts after the last SASE3 undulator cell. (2) There is no matching section between the system of planar undulators and the system of helical undulators. (3) The optics in the afterburner section is determined by the optics in the planar section of SASE3. (4) The space of 2.6 m is reserved for the housing of the APPLE X undulator. (5) Two undulators are installed between the quadrupoles. (6) A 1.1 m long intersection is located between all undulators. (7) Each intersection contains a phase shifter, a beam position monitor, a beam loss monitor, an absorber, and elements of the vacuum system. (8) Every second intersection also contains a quadrupole. (9) The FODO period length is: 4 × (1.1 m + 2.6 m) = 14.8 m.

THE PARAMETERS OF THE UE90 APPLE X UNDULATOR

The APPLE X undulator is an improved version of the Delta undulator rotated 45° along the magnetic axis of the undulator. It provides the possibility to control the K parameter both by shifting the magnetic structures relative to each other and by changing the gap between the magnetic structures.

The magnetic structure of helical undulators was designed to overlap the working range of planar undulator U68. The full length of the UE-90 magnet structure is 1.98 m, the undulator period length is 90 mm, the gap variation range is 12.5 −33.6 mm, the longitudinal shift range of each magnet array is ±45 mm, and the permanent magnets material is NdFeB with the nominal remanent field of 1.26 T.

Figure 1 shows the energy ranges generated with the planar U68 and helical UE-90 undulators for different electron beam energies. The distinct advantage of the APPLE X undulator is the ability to change the radiation energy by adjusting the gap. This results in a significantly higher field uniformity compared to a fixed-gap delta undulator, where the field can only be controlled by shifting the magnetic structures relative to each other, resulting in large field gradients. This requires extremely small tolerances for the alignment of the fixed-gap undulator system and makes an alignment of extended systems almost impossible.

Table 2: Photon Energy and the K Value Ranges

Polarization mode	LH/LV/C+/C-	Linear 45°
K-Range	9.59 − 3.06	6.76 − 2.16
Photon Energy Range [keV]		
@8.5 GeV	0.163 − 1.341	00.320 − 2.281
@11.5 GeV	0.299 − 2.455	0.585 − 4.176
@14 GeV	0.443 − 3.639	0.868 − 6.189
@16.5 GeV	0.615 − 5.054	1.205 − 8.597
@17.5 GeV	0.692 − 5.685	1.356 − 9.670

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Table 2 presents the photon energy ranges generated by the UE-90 undulator by varying only the gap. The magnetic field simulations for linear horizontal (LH), linear vertical (LV), circular clockwise (C+), circular anticlockwise (C-), and 45° linear polarizations have been performed using the Radia program [9].

VACUUM CHAMBER DESIGN

The high repetition rate, up to 27000 pulses per second, of the EuXFEL electron accelerator imposes additional requirements on the design of the vacuum chamber. The results of the simulations show that the maximum value of the thermal load on the walls of the vacuum chamber from synchrotron radiation and the dissipation of the wakefield is ~ 5 W/m. This will lead in the course of ten minutes to an increase in the temperature of the vacuum chamber by about two degrees. The increase of the vacuum chamber temperature will eventually lead to a change in the K parameter of the undulator. This causes the need for cooling of the vacuum chamber.

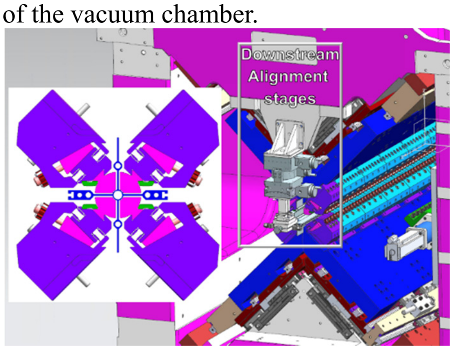

Figure 2: Layout of the alignment stages and a cross-section of the vacuum chamber surrounded by four magnetic structures at the minimum gap.

The design of the vacuum chamber is shown in Fig. 2. The vacuum chamber is made of aluminum alloy by extrusion. This makes it possible to use the existing cooling system of the vacuum chambers of planar undulators. The vacuum chamber has a cross-section in the shape of a cross. This shape provides high strength. FEM analysis shows that the sag is less than 300 μm if it is mounted in two points, on both sides of the undulator. This allows an easy alignment of the chamber and avoids unwanted contact between the chamber and magnets at a minimum clearance. There are six holes along with the electron beam chamber. Four of them are used for placing the horizontal and vertical correction coils and the other two, of smaller diameter, are used for water cooling. The ~ 8 W/m additional heat load, created by the Joule effect of the correction coils, placed along the chamber will be dissipated by water cooling. The vacuum chamber alignment system allows horizontal and vertical translations in the range of at least ±5 mm with a resolution of 10 μm and also rotation around the longitudinal axis of the chamber in the range of at least ±10° with a resolution of 0.01°. The vacuum chamber will be aligned relative to the magnet structure quadrants on either side of the undulator. The distance will be measured using capacitive sensors with a submicrometric resolution.

STATUS AND THE SCHEDULE OF THE PROJECT

Modifications to the electron beam optics of the accelerator as well as necessary changes to the tunnel infrastructure were carried out during the 19/20 and 20/21 winter shutdowns. The electron beam diagnostic systems have already been installed. The dosimetry system is in the process of development. The project is equipped with non-invasive and pulse-resolved polarization diagnostics.

At the time of writing, two undulator frames have been delivered. Both are equipped with magnetic structures. Preparations are underway to perform magnetic measurements and calibration of the UE90 undulators. The vacuum chamber together with the alignment components is expected to be ready for installation this fall. Installation of the undulators in the tunnel is scheduled to take place during the 21/22 winter shutdown. Simultaneously, work is underway to implement the control system. Commissioning of the helical afterburner is expected by mid-2022.

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