ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-TUPOPT014

THE STATUS OF THE SASE3 VARIABLE POLARIZATION PROJECT AT THE EUROPEAN XFEL

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Abstract

The undulator systems at the European XFEL consist of two hard X-ray systems, SASE1 and SASE2, and one soft X-ray system, SASE3. All three systems are equipped with planar undulators using permanent neodymium magnets. These systems allow the generation of linearly polarized radiation in the horizontal plane [1]. In order to generate variable polarization radiation in the soft X-ray range, an afterburner is currently being implemented behind the SASE3 planar undulator system. It consists of four APPLE-X [2, 3] helical undulators UE90. The project, called SASE 3 Variable Polarization, is close to being put into operation. All four helical undulators have been installed in the tunnel during the 2021-2022 winter shutdown. This paper describes the status of the project and the steps toward its commissioning. It also presents lessons learned during the implementation of the project.

CHARACTERISTICS OF THE HELICAL AFTERBURNER

The basic principle of the project is the possibility of using planar undulators to generate a micro-bunched electron beam. This beam is then directed to a system of helical undulators, which generate a laser emission of the desired polarization. Based on this, the technical characteristics of the helical undulators were calculated so that the energy spectrum of photons generated by the helical undulators overlapped the energy spectrum generated by the planar undulators. Simulation spectra of the photons generated by the helical undulator and comparison with the spectrum generated by the planar undulators for different energies of the electron beam are presented in detail in [4]. After the magnetic measurements, the boundary values of the K parameters of the undulators were determined. These values for different types of polarization are presented in Table 1. It also shows the photon energy ranges generated by the UE-90 undulator by varying only the gap for linear horizontal (LH), linear vertical (LV), circular clockwise (C+), circular anticlockwise (C-), and 45° linear polarization modes. It should be mentioned that the maximum photon energy for the SASE3 beamline transport system is 3 keV.

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Table 1: K Values and Generated Photon Energies

Polarization mode	LH/LV/C+/C-	Linear 45°/135°
K-Range	9.40 − 3.37	6.62 − 2.36
Photon Energy Range [keV]		
@8.5 GeV	0.169 − 1.141	0.332 − 2.012
@11.5 GeV	0.309 − 2.088	0.608 − 3.684
@14 GeV	0.457 − 3.095	0.902 − 5.459
@16.5 GeV	0.635 − 4.299	1.252 − 7.583
@17.5 GeV	0.715 − 4.835	1.409 − 8.530

Magnetic Measurements

Magnetic measurements of the undulator were performed using a Self-Aligned Field Analyzer with Laser Instrumentation (SAFALI) system designed and provided by Paul Scherrer Institute (PSI). The magnetic field was measured using a Senis 3-Axis Hall Probe I3C-03D. Two robots mounted on either side of the undulator were used to shim the magnets. These robots allowed shimming the magnets of both upper and lower magnetic structures. More details about the program and the results of magnetic measurements for UE90 undulators presented in [5].

FINDINGS AND CORRECTIONS

Initial measurements and calibration of the undulator were performed for the LH polarization mode. A strong, unexpected change in the magnetic field integrals was observed during the measurements in LV1 mode.

13th Int. Particle Acc. Conf. IPAC2022, Bangkok, Thailand JACoW Publishing
ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-TUPOPT014

In order to study the problem, the measurements of the magnetic field integrals at the LV1→C-→LH→C+→LV2 transition were carried out. The measurements showed a jump change in the field integrals in the region of circularly polarized C- and C+ modes (see Fig. 1).

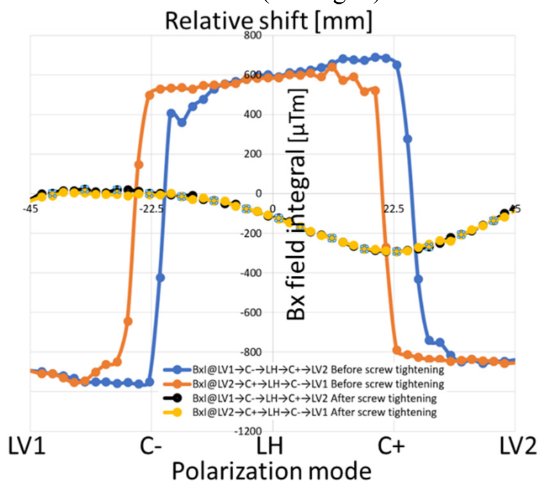

Figure 1: Bx field integral by transition LV1→C-→LH→C+→LV2 and LV2→C+→LH→C-→LV1 before and after tightening the fixing screw.

During the transition LV1→C-→LH mode and further LH→C+→LV2 a constant number of clicks could be heard. In addition, during the transition LV1→C-→LH→C+→LV2 and back LV2→C+→LH→C-→LV1, a hysteresis of the jump change in the field integral was observed.

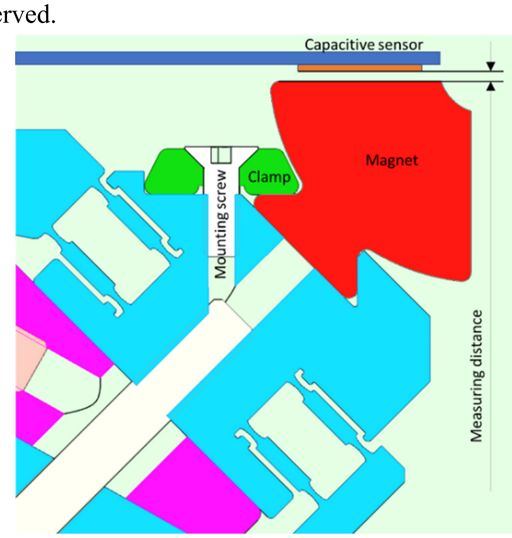

Figure 2: Mechanical measurements setup.

After a series of magnetic and mechanical measurements, the suspicion fell on a mechanical instability of the mounting of the magnets. To confirm this hypothesis, mechanical measurements of one of the suspected magnets relative to the girder on which this magnet was mounted were made (Fig. 2).

The measurements were performed using a capacitive sensor inserted in the gap between the magnetic structures. The distance between the sensor and the magnet was measured during the LV1→C-→LH→C+→LV2 transition. The results showed that the magnet was displaced by approximately 180µm in a stepwise manner at the point of change of the magnetic field, which corresponds to the circularly polarized mode (see Fig. 3). After clamping the magnet with a large force applied to the fixing plate, by increasing the torque of the fixing screw to ~2 Nm, the magnet jumping displacement was eliminated. The residual deformation of ~40µm is due to elastic deformation of the fastening mechanism and is approximately the same for all magnets.

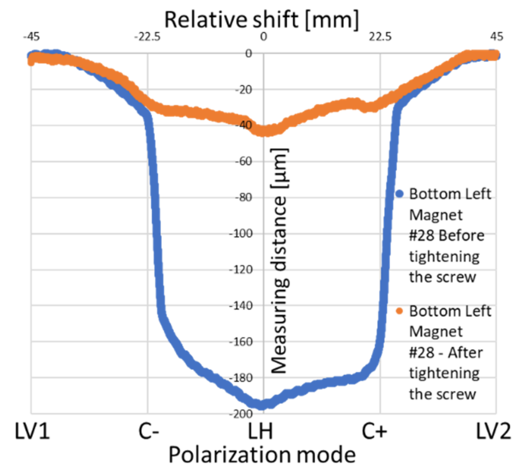

Figure 3: Displacement of the magnet measured by transition LV1→C-→LH→C+→LV2 before and after tightening the fixing screw.

Further magnetic measurements showed no jump change in the field integrals at the transition of the LV1→C-→LH→C+→LV2 polarization mode. The hysteresis of the magnetic field integral also disappeared at the transition LV1→C-→LH→C+→LV2 and back LV2→C+→LH→C-→LV1 (Fig. 1).

After eliminating the problem, the question arose as to how stable the mechanical magnet mounting system is and whether it is susceptible to plastic deformation. For this purpose, 9000 transitions LV1→C-→LH→C+→LV2 and back LV2→C+→LH→C-→LV1were performed at minimum gap. The following magnetic measurements showed no change in the performance of the undulator and had no effect on its calibration.

TEST OF MECHANICAL STABILITY OF THE UNDULATOR

After correcting the above problem by further tightening the screws on all of the undulators, serial magnetic measurements and calibration of the undulators was performed on all four undulators. The final parameters of the undulators were close to each other and were within the specification [5]. After calibration of the last undulator, another test was performed to verify the stability of the mechanical and magnetic properties of the undulator. This undulator was removed from the laboratory using a crane and placed on the transport pedestals. A test drive of the undulator was carried out using an air cushion vehicle designed for the installation of the undulators in the tunnel.

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Afterwards, the undulator was brought back to the lab with the crane. Subsequent magnetic measurements showed that the difference between the parameters of the undulators before and after this procedure did not exceed the measurements error.

VACUUM CHAMBER INSTALLATION AND ALIGNMENT

One more successful experience was gained by the incorporation of a new vacuum chamber developed for the UE90 undulators [6].

The vacuum chamber was installed before transporting the undulators to the tunnel. The horizontal and the vertical compensation coils were integrated into the vacuum chamber. The vacuum chamber, equipped with the coils and prepared for water-cooled connection, was inserted into the gap between the magnetic structures that was open to the maximum. It was then mounted to the alignment stations on either side of the undulator. These stations allow horizontal and vertical translation of ±5 mm with a resolution of 10 µm and rotation of ±10° with a resolution of 0.01º. A specially designed system of capacitive sensors measuring the distance between the surfaces of the magnets and the vacuum chamber was used for feedback during the vacuum chamber alignment [6]. The alignment was considered complete when the value deviations for all measured channels were less than 100µm. Experience with the UE90 undulators has shown that the maximum deviation does not exceed 60µm. After the alignment was completed, the gap of the undulator was set to its minimum position. Final verification of no contact between the vacuum chamber and the magnets was performed by pulling a 60 µm thick Kapton film through the gap between the magnetic structures and the vacuum chamber.

The stability of the chamber, the simplicity of the alignment and positioning measurement systems allowed the installation and final alignment of the vacuum chamber to be completed within a few hours.

COMMISSIONING OF THE HELICAL AFTERBURNER

All four undulators were installed in the tunnel during the winter shutdown of 2021/2022. They were connected to the control system and prepared for commissioning. The commissioning program was designed to use beam time during the so-called machine development weeks. However, the helical afterburner was not to prevent users from conducting experiments between the aforementioned weeks. For this purpose, the undulators were set up in the so-called zero-light mode. In this mode the magnetic structures are set in a position in which the K parameter is very close to zero and the compensation coils are loaded with values which result in a minimal deflection of the electron beam from its orbit. This mode was used during the first passage of the electron beam through the system of four APPLE-X undulators. The compensation coils were loaded with the values obtained during magnetic measurements in the laboratory. The first pulses of the 14 GeV electron beam passed through the new undulator system without any losses.

During the following machine development week, calibration measurements were performed for all compensation coils. Beam deflection measurements were also made when magnetic fields measured in the laboratory for the C+ mode were applied to these coils. These measurements showed that using these values, the maximum deflections did not exceed 20µrad.

The first lasing was obtained on the 5th of April during the second week of machine development. After installing the planar undulators in the reverse tapered position and tuning the APPLE-X undulators to the resonance frequency of 900 keV, the lasing in C+ mode was obtained immediately. By optimizing the beam orbit, the position of the phase shifters, and the reverse tapering value, a 30-fold increase in the intensity of the circularly polarized light relative to the linearly polarized light generated by the planar undulators was achieved (Fig. 4). The average pulse energy was 800µJ. After that, lasing was obtained at the same frequency in C-, 45°, LV and LH modes. On the same day lasing was also obtained at 700 keV for the C+, C-, and LH modes.

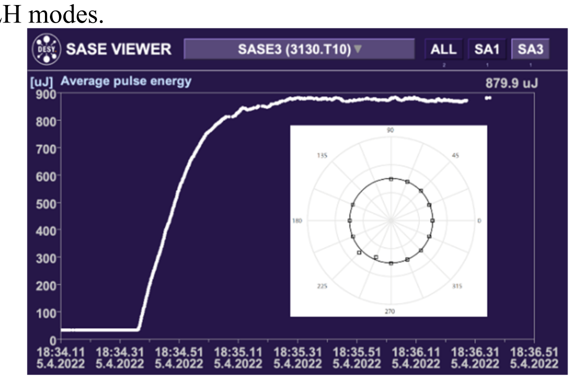

Figure 4: Intensity increase of circularly polarized radiation after tuning the APPLE-X undulators to 900 keV resonance frequency.

A further commissioning program unfortunately was not carried out. The reason is the failure of a large number of linear and rotary encoders, which are used to determine the position of the gap and the longitudinal shift of the girders. The suspected reason for these failures is excessive gamma radiation in the area of the helical afterburner. At the time of this writing, measures have been taken to eliminate the causes of the increased radiation, build shields for the encoders, and repair or replace the failed encoders in the shortest possible time. Upon completion of this activity, the further commissioning program will continue. The main objectives are, firstly, to suppress the linearly polarized radiation from the planar undulators and achieve a high level of ~99.9% of the radiation generated by the afterburner, and secondly, to prepare the afterburner for smooth operation for users.

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ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-TUPOPT014

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