UPCOMING INSERTION DEVICES AT MAX IV FACILITY

H. Tarawneh, M. Muradi, M. Holz, MAX IV Laboratory, Lund, Sweden

Abstract

Currently, 17 Insertion Devices (IDs) are in operation at the MAX IV facility. The soft X-ray undulators are based on the 3 APPLE II undulator at the 3 GeV ring, 4 APPLE II and 1 planar undulators at the 1.5 GeV ring, and the hard X-ray IDs are based on room-temperature in-vacuum technology at the 3 GeV ring and the Short Pulse Facility. A recently funded Tomography beamline for materials science at the 3 GeV ring will utilize two sources within the same straight section: a short-period cryogenic permanent magnet undulator (CPMU) with a 14 mm period length for nano-tomography and a 3 T 3-pole wiggler for micro-tomography. Both IDs are currently in production, with installation planned for summer 2027. Further development of a new medical-imaging beamline covering the energy range 15–70 keV at the 3 GeV ring. At the 1.5 GeV ring, a new APPLE II undulator providing polarization control starting at 43 eV photon energy is foreseen to replace an older planar undulator. In this paper, we present the parameters of these upcoming insertion devices and provide estimates of their expected performance.

INTRODUCTION

The MAX IV Laboratory operates a diverse set of insertion devices (IDs) covering a wide range of photon energies and experimental techniques, with ongoing developments aimed at extending performance and functionality. Existing IDs at both the 3 GeV and 1.5 GeV storage rings already provide high-brilliance radiation for a broad range of applications. However, new beamlines and planned upgrades require advanced ID concepts with improved performance, flexibility, and spectral characteristics. This paper presents an overview of upcoming insertion devices at MAX IV, including new installations for the TomoWISE beamline and the future MedMAX beamline, upgrades to the FlexPES insertion device, and modifications to the BALDER wiggler. These developments aim to enhance spectral quality, extend energy coverage, and introduce new operational capabilities such as polarization control and multi-scale imaging.

ID FOR TOMOGRAPHY BEAMLINES

The TomoWISE beamline is a newly funded tomography beamline at the 3 GeV storage ring, designed to cover both nano- and micro-tomography within a single straight section. To achieve this, two complementary insertion devices will be installed.

Cryogenic Permanent Magnet Undulator (CPMU) technology will be used for the first time at the MAX IV 3 GeV ring. The CPMU is a short-period undulator with a period length of 14 mm [1]. The CPMU design is based on using Pr2Fe14B for magnet blocks and Vanadium Permendur for pole material. Operating at cryogenic temperatures, it provides a higher magnetic field strength than room-temperature devices. This allows for higher photon energies and improved brilliance, making it well-suited for high-resolution nano-tomography applications.

The second source is a 3 T, 3-Pole Wiggler (3PW) designed for microtomography. It provides a broad spectrum with high photon flux, enabling fast imaging of larger samples. The combination of CPMU and 3PW enables TomoWISE to span multiple length scales within a single beamline, as shown in the schematic view in Fig. 1.

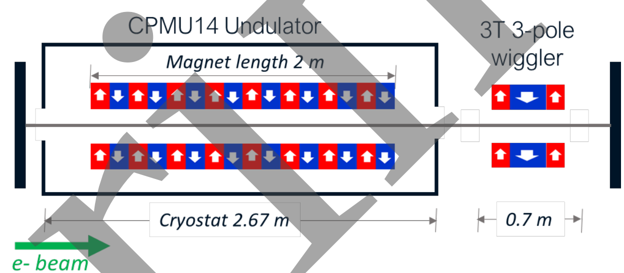

Figure 1: Schematic layout of the two IDs at the 3 GeV ring straight section with available spaces.

The two sources are not allowed to operate simultaneously, and hence, the wiggler gap is movable to allow full neutralization of the wiggler field to operate the CPMU. Both devices are currently in production, with installation planned for summer 2027. Table 1 summarizes the main parameters of the two ID sources. The on-axis field profile along the wiggler is shown in Fig. 2 [2].

Table 1: TomoWISE Insertion Devices Parameters

Parameter	CPMU	3PW
Period length, mm	14	412*
Magnetic gap, mm	3.8	11
Field, T	1.41	3
No. of Periods	143	1 (pole)
Power @500 mA, kW	11.1	1.6
Energy Range, keV	10–65	

(*) Total magnetic length of wiggler

The wiggler vacuum chamber is a NEG-coated chamber with an inner vertical dimension of 8 mm. Fig. 3 shows the CPMU brilliance using the baseline machine parameters of the 3 GeV MAX IV storage ring and the wiggler flux at minimum gap of 11 mm into an aperture of 1 × 0.1 mrad^2. The CPMU flux estimate at minimum gap into an aperture of 25 × 25 μrad^2 is shown in Fig. 4.

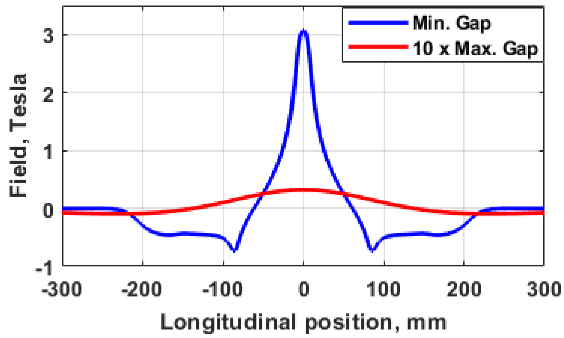

Figure 2: Magnetic field along the 3PW for min. gap and max. gap of 11 mm and 400 mm, respectively.

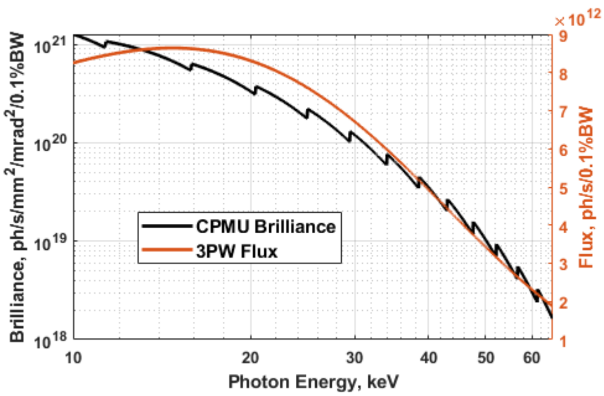

Figure 3: TomoWISE CPMU brilliance curve and the flux of 3PW at minimum gap within an aperture 1 × 0.1 $mrad^2$.

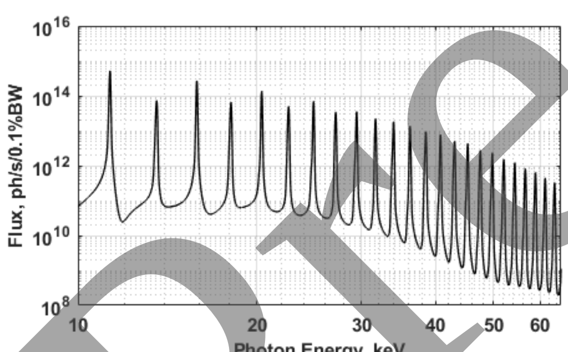

Figure 4: The CPMU flux at minimum gap into slit size of 25 × 25 μrad^2 based on the 3 GeV ring's beam parameters.

An ongoing conceptual design work of a new biomedical imaging beamline, MedMAX, to visualize complex structures and processes in life sciences and soft matter down to the sub-µm spatial resolution using hard X-ray tomographic microscopy. So far, the same scheme of two ID sources, similar to TomoWISE, is foreseen for an energy range of 15 – 70 keV, but with a shorter period length for the new CPMU.

BALDER WIGGLER UPGRADE

BALDER is a hard X-ray absorption spectroscopy beamline and the only wiggler-based beamline at the MAX IV 3 GeV storage ring. Its current in-vacuum wiggler delivers a wide-band spectrum covering approximately 2.4 to 40 keV. The wiggler operates at a minimum magnetic gap of 4.5 mm, achieving a peak field of 2.4 T with a period length of 50 mm. While this enables access to low photon energies, the emitted spectrum exhibits undulator-like structures at the low-energy side. These spectral ripples, with amplitudes of a few percent, arise from incomplete merging of harmonics despite a high deflection parameter, K-value of 9. Such non-uniformity can affect absorption spectroscopy measurements. Previous studies have investigated methods to smooth the spectral ripples [3], including angular and energy acceptance, electron beam divergence and energy spread, magnetic field imperfections, gap tapering, and beam tilting. Experimental results show that increasing energy spread and introducing controlled field imperfections can effectively reduce spectral modulation. Current upgrade efforts focus on modifying the wiggler's magnetic circuit to introduce controlled phase errors and suppress harmonic interference. Two main approaches are under investigation: randomization of magnet-pole blocks using mechanical shims and the introduction of linear or nonlinear longitudinal gradients, as shown in Fig. 5.

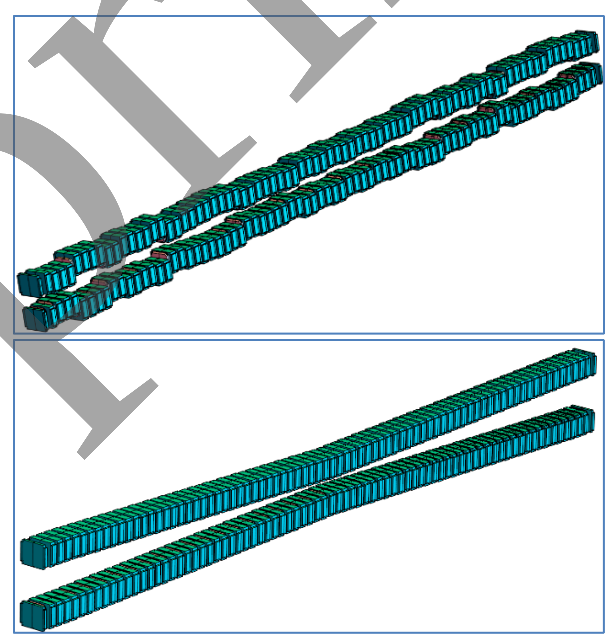
Figure 5: 3D model of the wiggler magnet-pole blocks with randomized mechanical shims (upper) or linear gradient (bottom) along the wiggler girders.

Both approaches aim to generate an RMS phase error exceeding 20 degrees, effectively smoothing the emitted spectrum. These modifications must remain within strict field quality tolerances to preserve beam dynamics. These approaches, in addition to the tapering feature, may further improve spectral smoothness while maintaining acceptable power loads on optical components. Fig. 6 shows the effect of field imperfection only for the linear-gradient case, as an example.

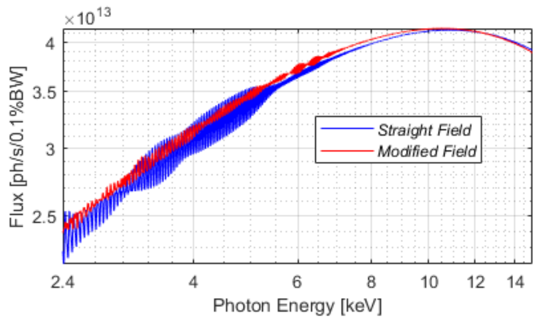

Figure 6: Flux ripples smoothing due to field imperfection only.

NEW APPLE II AT 1.5 GEV RING

The existing undulator of the FlexPES beamline is an old planar undulator transferred from the decommissioned MAX II ring and refurbished prior to installation at the MAX IV 1.5 GeV ring in 2016. An upgrade of the undulator with an APPLE II undulator [4], which can offer the required photon energy range and a new feature at the beamline of full polarization control. The installation of the undulator with a new vacuum chamber is planned for summer 2028. The required minimum photon energies of 43 eV for horizontal polarization and 80 eV for vertical polarization can be achieved with a period length of 50 mm, a magnetic remanence (Br) of 1.26 T, a minimum magnetic gap of 11 mm, and 49 full periods. Each block has dimensions of 30 × 30 × 12.5 mm³ and includes a 5 mm cut-out at two of its corners. The four sub-girders of the APPLE II structure are designed to move longitudinally along the undulator axis within ±λ/2 to allow parallel and anti-parallel motion of the two diagonal sub-girders. This motion scheme will allow all possible operational modes of helical and linear inclined modes, or a combination of the two, to compensate for polarization state distortions introduced by beamline optical components at low photon energy. Fig. 7 shows the expected flux based on the machine parameters of the 1.5 GeV MAX IV storage ring.

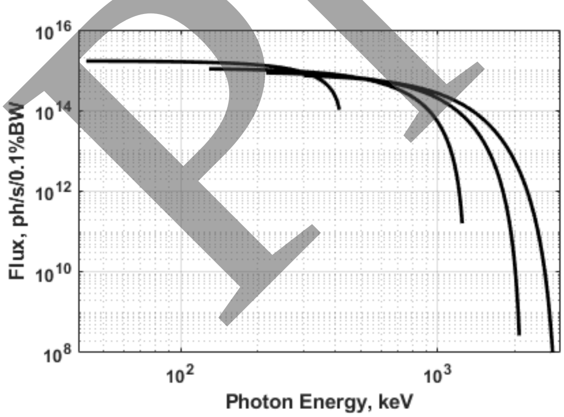

Figure 7: FlexPES APPLE II Flux for the first four odd harmonics.

CONCLUSION

The ongoing and planned developments of insertion devices at the MAX IV Laboratory represent a significant step forward in expanding the facility's scientific capabilities. The introduction of cryogenic permanent-magnet undulators (CPMUs) and a high-field wiggler will enhance spectral quality, increase photon flux and brilliance, and extend the accessible energy range to 70 keV. The dual-source concept offers greater experimental flexibility. In parallel, the upgrade plan to the existing BALDER wiggler demonstrates an effective approach to improve spectral smoothness. Replacing the old FlexPES undulator with an APPLE II structure will not only cover the required energy range but also introduce full polarization control, giving users a new feature and greater flexibility.

REFERENCES

[1] J. Campmany *et al.*, "Design of Front End and a 3-Pole-Wiggler as a Photon Source for BEATS Beamline at SESAME", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 324-326. doi:10.18429/JACoW-IPAC2021-MOPAB086

[2] T. Hara et al., "Cryogenic permanent magnet undulators," *Phys. Rev. ST Accel. Beams*, vol. 7, no. 5, May 2004. doi:10.1103/physrevstab.7.050702

[3] K. Klementiev, H. Tarawneh, and P. F. Tavares, "Wiggler radiation at a low-emittance storage ring and its usage for X-ray absorption spectroscopy," *J Synchrotron Rad*, vol. 29, no. 2, pp. 462–469, Jan. 2022. doi:10.1107/s1600577521012844

[4] S. Sasaki, K. Kakuno, T. Takada, T. Shimada, K. Yanagida, and Y. Miyahara, "Design of a new type of planar undulator for generating variably polarized radiation," *Nucl. Instrum. Methods Phys. Res. A*, vol. 331, no. 1–3, pp. 763–767, Jul. 1993. doi:10.1016/0168-9002(93)90153-9