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ACCEPTANCE TESTS AND INSTALLATION OF THE IVU AND FRONT END FOR THE XAIRA BEAMLINE OF ALBA

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Abstract

XAIRA is a new beamline being built at ALBA synchrotron for macromolecular crystallography (MX) devoted to the study of small biocrystals. It aims at providing a full beam with a size of 3×1 μm^2 FWHM (h×v) and a flux of >3×10^{12} ph/s (250 mA in Storage Ring) at 1 Å wavelength (12.4 keV) to tackle MX projects for which only tiny (<10 μm) or imperfect crystals are obtained. Besides, XAIRA aims at providing photons at low energies, down to 4 keV, to support MX experiments exploiting the anomalous signal of the metals naturally occurring in proteins (native phasing), which is enhanced in the case of small crystals and long wavelengths. To this end, an in-vacuum undulator has been built by a consortium between Kyma and Research Instruments companies. In this paper we present the results of the Acceptance Tests and the installation of the device.

UNDULATOR REQUIREMENTS

In order to fulfill the scientific requirements, a hybrid, in-vacuum and long undulator has been designed, with parameters detailed in Table 1.

Table 1: Main Parameters of XAIRA Undulator

Undulator type	In-vacuum
Magnetic configuration	Planar hybrid
Magnetic material	NdFeB
Pole material	Permendur
Period length	19.9±0.02 mm
Number of periods	115
Maximum magnetic length	2.3 m
Magnetic minimum gap	5.2 mm
Minimum physical gap	4.8 mm
Gap range (magnetic)	5.2 mm to 30 mm
Min. effective K at min. gap	2.1085

ID DESIGN

Blocks are box-type with chamfers in edges allowing clamp fixations and longitudinal chamfers to prevent demagnetization. Mechanical tolerances have been assumed to give changes in the peak field smaller than 0.1%. Selected magnetic material is NdFeB with remanence Br = 1.34 T and coercivity μ0HCJ ≥ 1.5 T. Poles are made of high permeability Vanadium Permendur.

The optimization of central pole leads to the block and pole dimensions specified in Tables 2 and 3. Shapes are shown in Fig. 1. The central part is shown in Fig. 2.

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Table 2: Magnetic Block Characteristics

Width	60.0 ± 0.05 mm
Height	40.0 ± 0.05 mm
Length	7.164 ± 0.02 mm
Transverse chamfer angle	45.00º
Transverse chamfer side	4.0 ± 0.02 mm
Longitudinal chamfer angle	45.00º
Longitudinal chamfer side	1.00 ± 0.02 mm
Remanent field	1.34 T
Permeability on axis	1.06
Transversal axis permeability	1.17

Table 3: Iron Pole Characteristics

Width	40.0 ± 0.05 mm
Height	40.0 ± 0.05 mm
Length	2.786 ± 0.02 mm
Transverse chamfer angle	45.00º
Transverse chamfer side	4.0 ± 0.02 mm
Longitudinal chamfer angle	45.00º
Ear width	4.0 ± 0.1 mm
Ear height	3.0 ± 0.1 mm

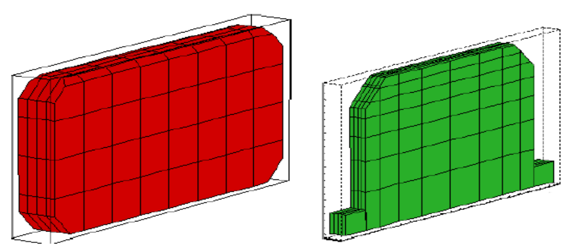

Figure 1: Shapes of blocks (red) and poles (green) in the hybrid design.

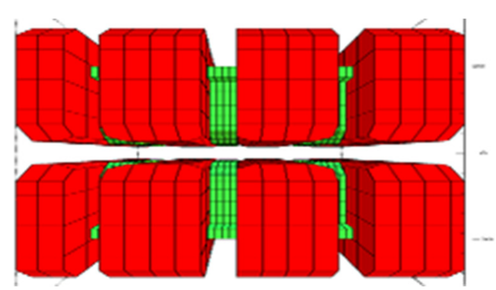

Figure 2: Arrangement of poles and blocks.

We modelled the whole undulator using RADIA [1]. According to the model the orbit is offset by -75.35 T·mm^2 corresponding to -7.53 μm for a 3 GeV electron beam. Poles have been optimized to obtain a good field region for $|x| \leq 10$ mm in which the field is uniform within 0.3%. Maximum field on axis is 1.2275 T.

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ACCEPTANCE TESTS

A key point in the performance of such undulator is the phase error. To carry out the experiments proposed by scientific case, the flux at 9th harmonic should be enough to make fast experiments.

To ensure this, the so called phase error should be less than 2.5º at least. Above this number, the interference is broken and the flux peaks reduce drastically their sharpness and peak value.

KYMA measured the magnetic behaviour out of vacuum after a hard process of shimming. This has taken a lot of time because the hybrid structure is difficult to model and therefore a number of iterations was required.

Finally, the results were as specified, with RMS phase error below 2.5º, as shown in Fig. 3.

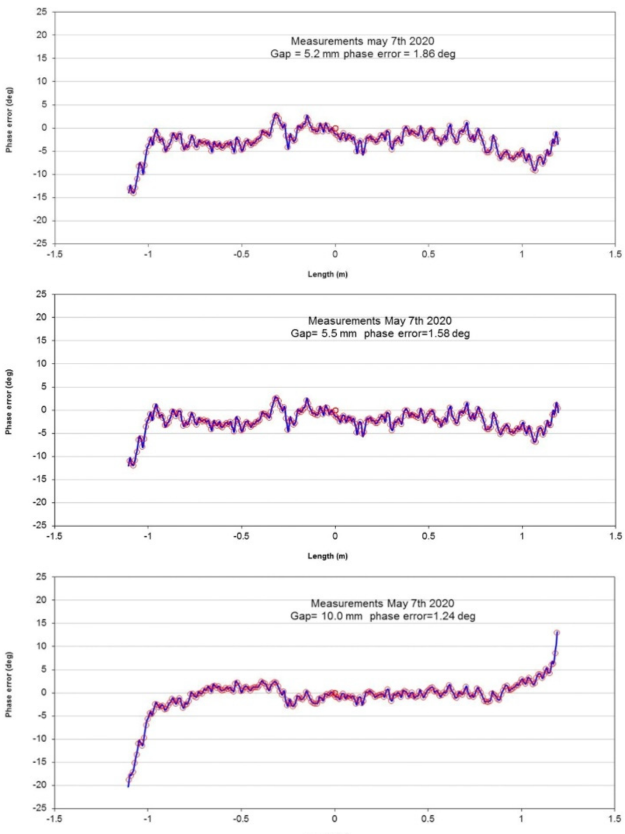

Figure 3: Phase error measurements at 5.2 mm, 8 mm and 15.2 mm gap. All of them show RMS below 2.5º.

According the measurements, the performance of the device is according with requirements. The instrument was received at ALBA premises at end of March 23rd 2020.

SAT in situ did not start until September 2020 because of pandemics situation. All SAT measurements have been carried out at ID magnetic laboratory at ALBA. Figure 4 shows the delivered undulator at ALBA premises.

Vacuum tests were done in October 2020 at ALBA ID lab. Pressure reached was 10^{-10} mbar, with no leaks detected. The RGA analysis was satisfactory, as shown in Fig. 5.

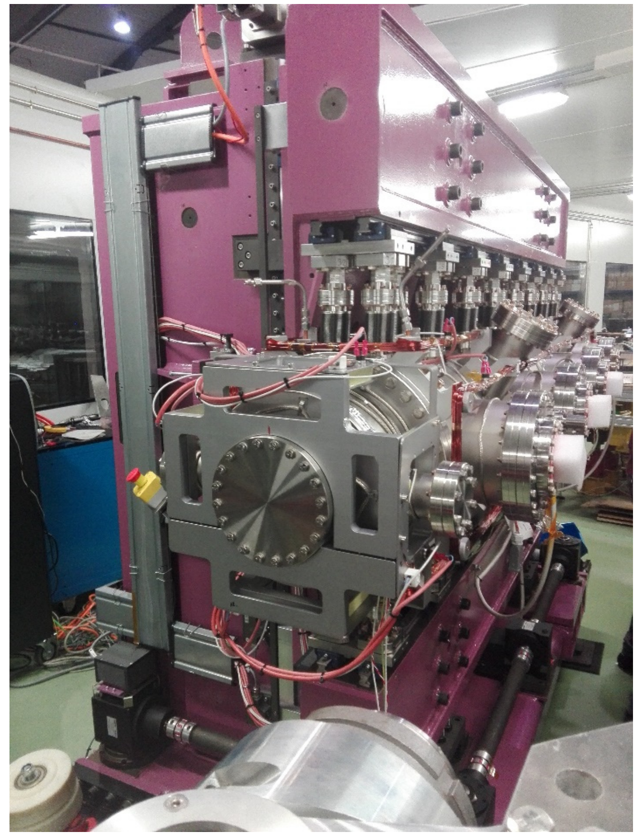

Figure 4: XAIRA undulator after SAT measurements including vacuum, magnetic field and EPS system.

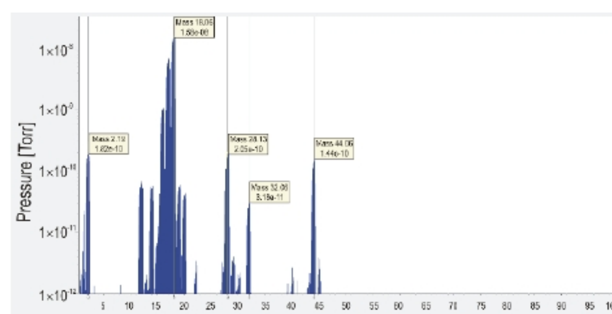

Figure 5: RGA analysis of residual gases in XAIRA vacuum chamber after its closure.

Hydraulic tests were carried out on November 18th 2020. The system resisted 16 bar of pressure and no inner leak has been detected. Set up is shown in Fig. 6.

Magnetic tests were carried out during October and November 2020 using the new Hall probe bench developed in-house to measure closed structures [2]. Correspondence between gap and field, reproduced with total similarity those measured by KYMA, as shown in Fig. 7.

The ID was installed in ALBA tunnel on Dec 2020, including a 2-week duration bake out at moderate temperature (external vacuum chamber ~90º C, internal magnet blocks ~50º C). All the hardware is ready to start delivering photon into the Front End (FE) by the end of June 2021.

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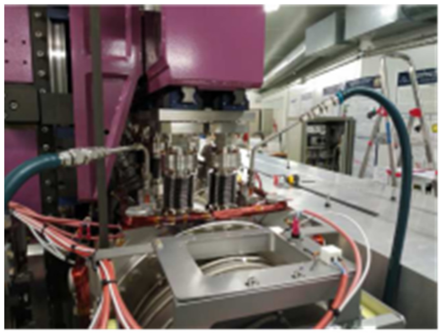

Figure 6: Set up for hydraulic tests in ALBA ID Laboratory carried out in November 2020.

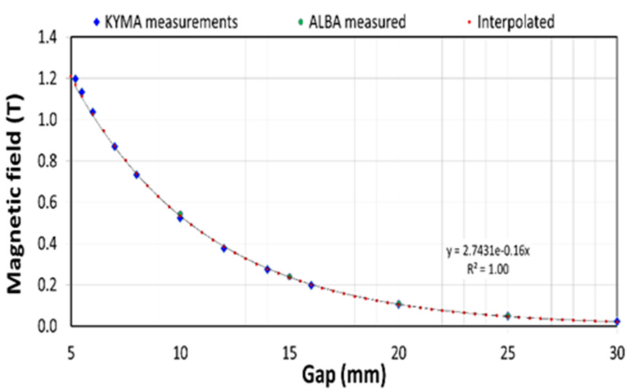

Figure 7: Correspondence between ALBA and KYMA magnetic field vs gap measurements.

FRONT END

For the structure of the FE we adapted the design at existing ALBA beamlines with an IVU as a source [3] to the enhanced power and on-axis power density delivered by XAIRA undulator. The main modification consisted in increasing the length of the power absorbing elements (fixed and movable masks) in order to distribute the photon beam's footprint over a larger area. The detailed characteristics of the FE were described in [4].

The FE has been manufactured by company FMB-Berlin GmbH (Berlin, Germany) and was delivered to ALBA on October 2019. Site Acceptance Tests were carried out and successfully passed during Nov-Dec 2019, and the equipment was installed inside the tunnel on summer 2020. On April 2021 a preliminary beam conditioning of the FE using the radiation from the dipoles adjacent to the ID was carried out. The proper conditioning using the photons from the ID itself is foreseen by June 13th.

CONCLUSION

Despite the length and the hybrid structure, the device has been shimmed to reach phase error values below the specified 2.5º, so we have demonstrated that without cryogenics the magnetic period and length of the designed photon source can cover the range 4 - 20 keV photon energies with optimized photon flux.

The manufactured insertion device fulfils therefore the two scientific aim of the beamline, namely, providing maximized flux at 12 keV photon energy for micro-MX experiments and an energy range down to 4 keV.

Thanks to this, the phase determination using the anomalous signal of low-Z elements (S, Cl, K, Ca) naturally present in proteins is feasible.

Despite the considerable larger total power (×2.4) and maximum power density (×1.8) delivered by this photon source compared to existing IVUs at ALBA, we have been able to adapt our standard FE for IVU sources with only some minor modifications affecting the length of the critical power absorbing elements.

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