Sub-20-nrad Stability of an LN_2-Cooled Vertical-Offset Double Crystal Monochromator

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Introduction

The continuous advance towards diffraction-limited synchrotrons and free-electron-laser (FEL) sources requires beamline components with ever-increasing optical and mechanical performance. One of the key aspects for the latter is the angular vibration amplitude, which determines the positional stability of the x-ray beam at the experiment. Nowadays, facilities world-wide are setting the goal for angular stability to 50 nrad rms and better. We present a vertically deflecting Double Crystal Monochromator (DCM) designed and built by AXILON and report the measured stability between 1st and 2nd crystal.

The AXILON vertical offset DCM

AXILON has developed a compact and rigid mechanical design for an LN_2 cooled vertically-deflecting DCM for the beamline ANATOMIX at Synchrotron SOLEIL. The layout of the beamline demands ultra-stable optics because of:

- the large lever arm of up to 150 m between DCM and location of the experiment
- the absence of a secondary source downstream of the DCM

Therefore one of the key parameters in the design is the stability and frequency characteristics of the crystal cage and the entire DCM system.

Key parameters for the DCM:

- Energy range — 4 to 40 keV with Si111
- Bragg range — 2.8 to 30°
- Power load — up to 425 Watts
- Power density — up to 18 Watts / mm² (projected)
- Offset — 20 mm (upwards)
- Cooling — cryogenic, 2nd crystal via braids
- Vacuum — 10^{-8} mbar
- Motion axes — horizontal, vertical, Bragg, gap, roll1, pitch2 with piezo
- Features — long 2nd crystal for up to 40 keV, in-situ interferometer setup with integrated feedback control

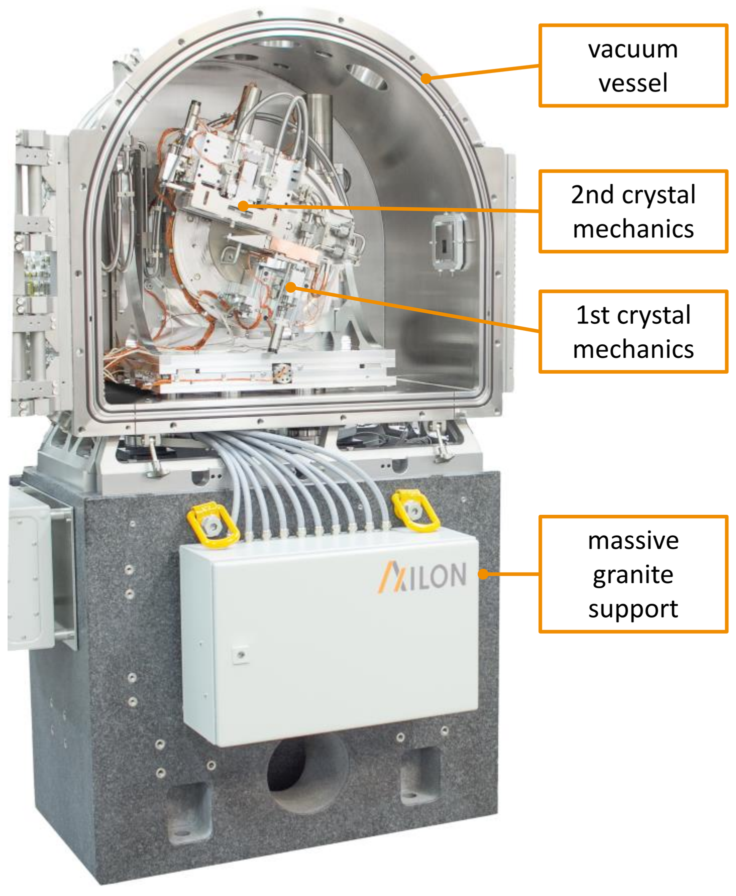

Fig. 1 – vertical offset DCM, completely mounted

The *anatomix* beamline at Synchrotron SOLEIL

With an accessible range of photon energies from 5 to 25 keV, a beam size up to 40 mm width, and two experimental stations covering length scales down to a resolution of 30 nm pixel size, the beamline ANATOMIX *(Advanced Nanotomography and Imaging with coherent X rays)* will give access to absorption and phase-contrast tomography of biological soft tissue up to several cm thickness, and to X-ray microscopy of biological samples and natural or advanced engineering materials. The beamline optics allows for an extended energy range from 4 to 40 keV and even 50 keV using the white beam [1,2].

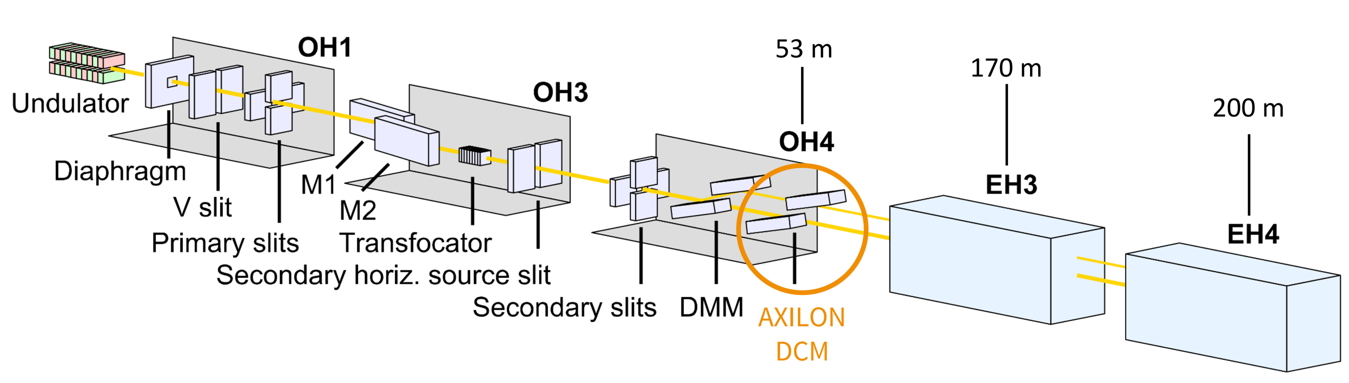

Fig 2: Schematic of ANATOMIX beamline optics. All elements shown except the diaphragm can be removed from the beam [1,2].

Key parameters of the beamline ANATOMIX [1,2]:

- Experim. techniques — parallel-beam full-field microtomography
  - absorption and inline phase contrast
  - X-ray grating interferometry (planned)

  full-field zone-plate microscopy (under commissioning)
  - absorption and Zernike phase contrast
- Source — U18 cryogenic in-vacuum undulator
- Energy range — 5 to 25 keV, up to 50 keV when using white beam
- Beam modes — filtered white beam, DCM ($\Delta E/E = 10^{-4}$), DMM ($\Delta E/E=10^{-2}$)
- Beam at sample — 40 x 40 µm² (zone plate microscopy) to 40 x 15 mm² (medium-resolution parallel-beam microtomography)

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[1] T. Weitkamp et al., Journal of Physics: Conf. Series **849** (2017) 012037

[2] www.synchrotron-soleil.fr/en/beamlines/anatomix

Factory metrology

AXILON's in-house testing capabilities enables the verification of mechanical specifications of each component in the factory:

- 3D dimension control and fiduzialization
- Full vacuum tests
- Standard axes performance checks (resolution, accuracy, repatability, parasitic motions)
- Interferometry down to the nm and nrad regime, under vacuum and cryogenic conditions

For the vertical-offset DCM the stability performance of crystal pitch and roll parallelism is measured in the factory with the in-situ differential interferometer setup under operating conditions:

- Vacuum level: 10^{-8} mbar
- LN_2 flow: variable from 0.8 to 5 l/min using the AXILON closed loop system ChillAX

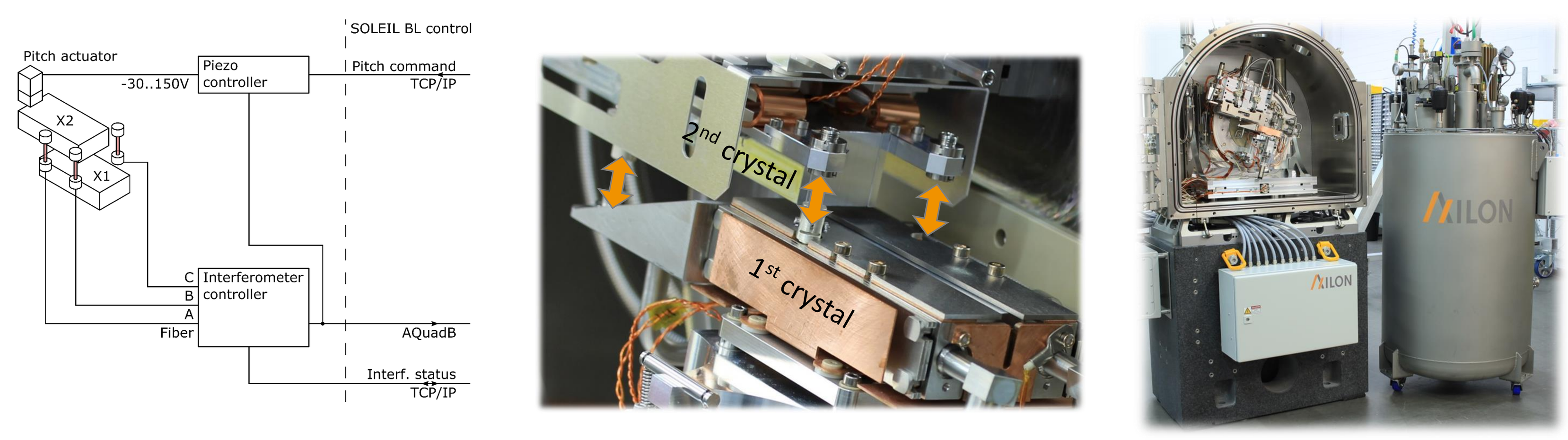

Fig. 3 – left: control scheme of interferometer setup, mid: detailed view of 1st/2nd crystal with interferometer setup, right: DCM with AXILON ChillAX

First commissioning results

Factory measurements for the ANATOMIX DCM show excellent stability performance meeting and exceeding the goal staying well below 50 nrad rms under operating conditions.

parameter	result
pitch stability (rms, 0.1 to 2,000 Hz):	15 nrad (up to ~500 Watts cooling capacity)
	< 25 nrad (up to ~ 1,000 Watts cooling capacity)
pitch stability (over 36h):	< 25 nrad
1st relevant resonance:	175 Hz

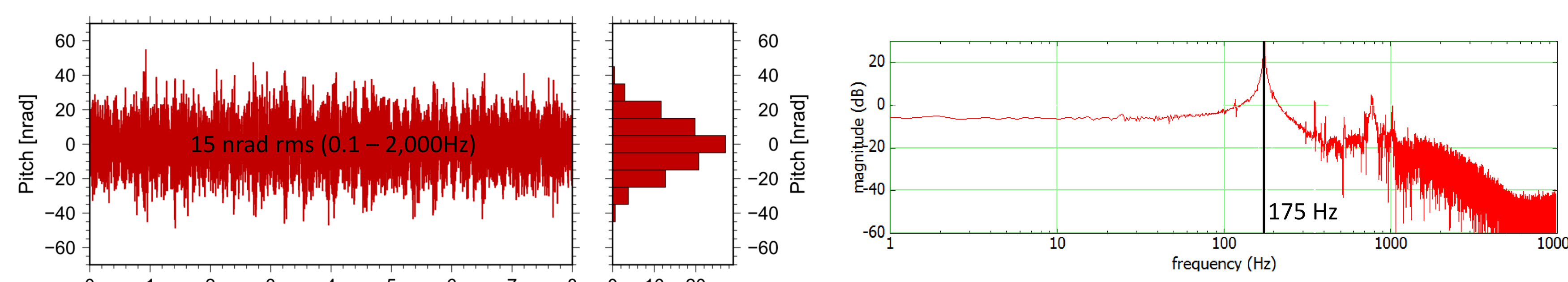

Fig. 4 – left: short term stability at 1.3l/min LN_2 flow, right: frequency spectrum of stability signal

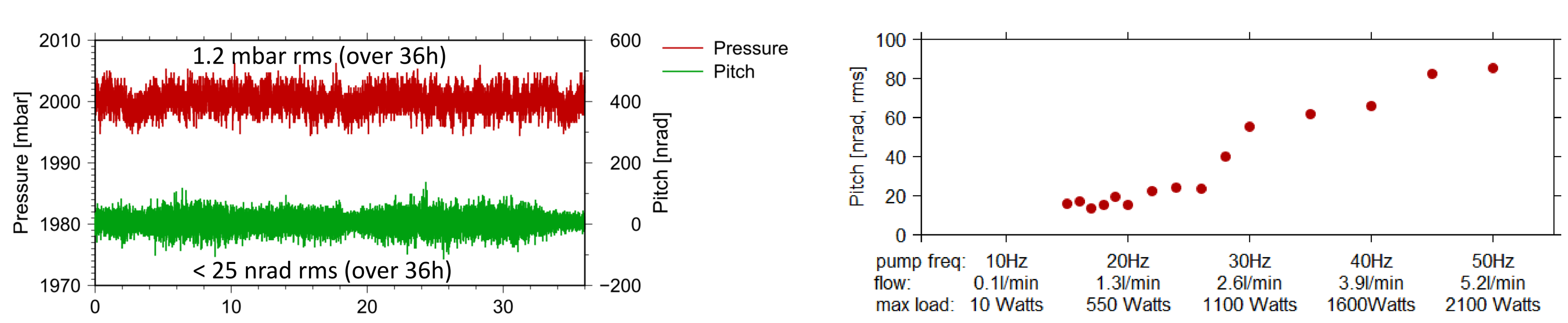

Fig. 5 – left: long term stability (ChillAX pressure and DCM pitch) at 2.3l/min LN_2 flow, right: pitch rms (0.1 to 2,000 Hz) stability vs LN_2 flow

Early beam stability measurements are consistent with factory interferometer measurements: Beam stability at an elevated LN_2 pump frequency of 41Hz (~4l/min LN_2 flow), corresponds to a pitch stability of 80 nrad rms (vs. ~65 nrad at the factory) neglecting all instability contributions of other sources.

In the next months, we expect further stability improvements with an adapted LN_2 flow during commissioning and optimization.

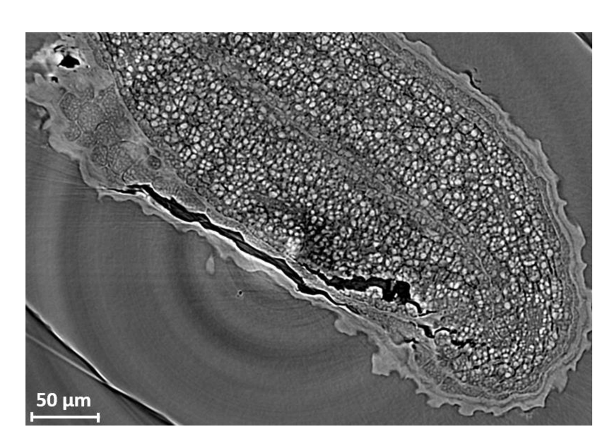

Fig. 6 – Microtomography slide through *Arabdiopsis*, taken with 10 keV mono beam 1 µm spatial resolution in reconstruction (sample courtesy C. Rivard, INRA Nates/SOLEIL)

Fig. 7 – sequence of beam images at sample location

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