

The tomography beamline *ANATOMIX* at Synchrotron SOLEIL

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Abstract. ANATOMIX is a 200-m-long undulator beamline for full-field tomography techniques at photon energies from 5 to 25 keV. It is currently under construction at Synchrotron SOLEIL, the French national light source near Paris. ANATOMIX will feature experimental stations both for parallel-beam microtomography (with a beam of up to 40 mm width) and for zone-plate transmission X-ray microscopy (down to pixel sizes of 30 nm) in absorption and phase contrast. The location of ANATOMIX on a canted straight section of the SOLEIL storage ring implies specific challenges for the design and operation conditions of the beamline. In this paper we present general design aspects and the status of construction.

1. Introduction

Since the end of the 1990s, synchrotron microtomography methods have become widely-used tools in biomedical research, materials science and other fields [1–3]. Today, several beamlines at synchrotron radiation facilities in Europe respond to the needs of tomography users [4–12].

To complement these stations, three beamlines at Synchrotron SOLEIL—*PSICHÉ* [13], *PUMA* [14] and *ANATOMIX*—offer full-field radiography and tomography in the hard X-ray range, or will do so in the near future. Table 1 shows their key parameters.

In this paper we give an overview of the *ANATOMIX* beamline, currently under construction. It is the longest beamline at SOLEIL (200 m) and is fully dedicated to radiographic and tomographic methods in

Table 1. Beamlines at Synchrotron SOLEIL for X-ray full-field radiography and tomography.

Beamline	<i>PSICHÉ</i>	<i>PUMA</i>	<i>ANATOMIX</i>
X-ray source	Wiggler	Wiggler	Undulator
Energy range (keV)	20 to 100	15 to 60	5 to 25
Max. beam size (mm ² , h×v)	15×5	20×10	40×10
Min. pixel size (nm)	≈ 500	≈ 500	≈ 30 (TXM); ≈ 500 (other)
Spectral beam modes	Filtered white, crystal mono	Filtered white, crystal mono	Filtered white, crystal mono, multilayer
Status	Operational	Expected 2018	Expected 2018



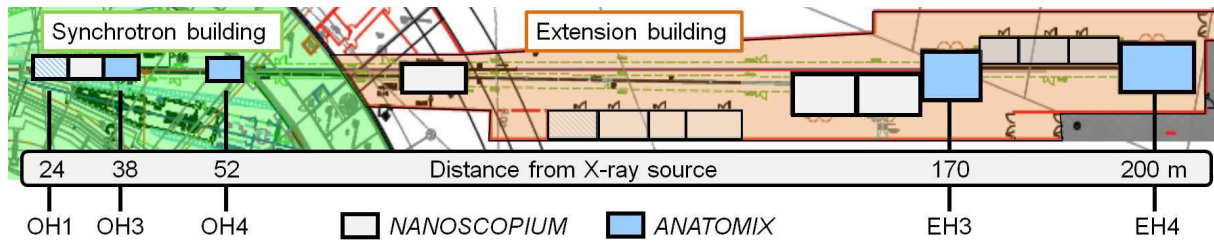


Figure 1. Floor plan of beamlines *NANOSCOPIUM* and *ANATOMIX*. Hutches are numbered jointly with *NANOSCOPIUM*. OH1, OH3, OH4, EH3, EH4 (blue) contain relevant instrumentation of *ANATOMIX*.

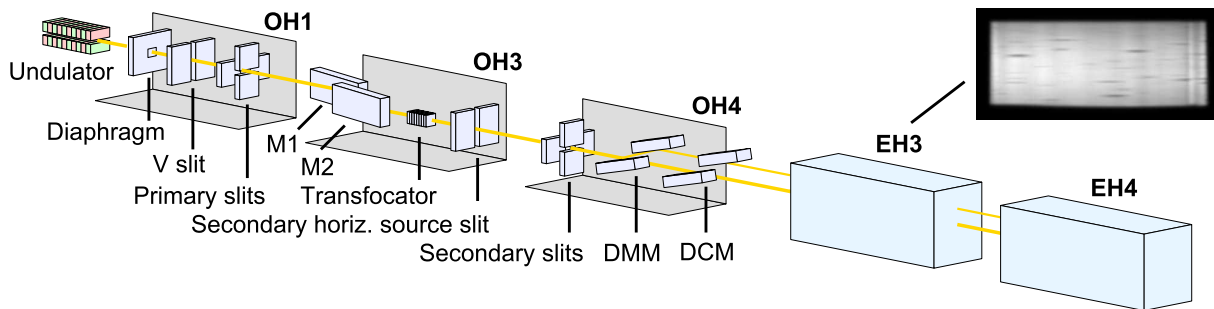


Figure 2. Schematic of *ANATOMIX* beamline optics. All elements shown except the diaphragm can be moved out of the beam path. (Attenuators and diagnostic devices not shown.) *Inset*: first beam in EH3, September 2016.

the hard X-ray range. It will provide stations for two methodologically different classes of experiments, to cover different ranges of length scales: (1) parallel-beam X-ray shadowgraphy, for spatial resolution down to the sub-micron range and (2) full-field transmission X-ray microscopy (TXM) down to a spatial resolution of 100 nm or less.

Both types of methods will be used both in absorption contrast and in phase contrast. For shadowgraphy, phase contrast will be accessible through propagation-based imaging [15, 16] and X-ray grating interferometry [17]. For the TXM station, Zernike-type phase contrast [18] is foreseen.

2. Technical details

ANATOMIX is located on a long straight section of the SOLEIL storage ring. It shares this section with the scanning nanoprobe beamline *NANOSCOPIUM* [19]. Each of the two beamlines takes photons from a canted undulator; the centers of both insertion devices are separated by 7 m, *ANATOMIX* being located on the upstream source. A specifically-developed electron-beam angle interlock [20] ensures that the stringent requirements on the stability of the electron-beam trajectory are always met. Together with a protective mask between the two insertion devices it prevents damage to the downstream undulator.

The photon emission axes of both insertion devices are separated by an angle of 6.5 mrad [21]. Two mirrors permanently inserted into the *NANOSCOPIUM* X-ray beam increase this separation to 26 mrad. The experimental hutches of both beamlines (and the monochromator hutch of *NANOSCOPIUM*) are located in a dedicated satellite building (Figure 1).

The optics concept is based on the principle that the direct white X-ray beam can be led all the way to the experimental stations—if desired, without any beam-steering optics or monochromatization. Optical elements to condition the beam spectrally and/or geometrically can be inserted as needed (Figure 2).

Table 2 lists the major beamline optics. In the first optics hutch (OH1), shared between the two

Table 2. List of important beamline elements. Distances are given from the center of the undulator.

Element	Distance (m)	Description	Hutch
Diaphragm	22.7	Rectangular aperture $2.5 \times 2 \text{ mm}^2$ (h×v).	OH1
Vertical slit	23.2	Horizontal aperture 100...300 μm , removable. Increases horizontal transverse coherence where needed.	
Primary slits	25.9	Define footprint on mirror and other optics.	
Attenuators	34.6	Protect transfocator and other downstream elements.	OH3
Mirror M1	35.3	Horiz. deflection. Useful length 400 mm. Bender for horiz. focusing (focal length 3.5 m). Coatings: B_4C , Rh, Pt. Grazing angle ≈ 3 mrad.	
Mirror M2	36.3	Horiz. deflection. Plane mirror, steers beam back into direction parallel to direct beam, offset 5 mm. Same length, angle and coatings as M1.	
Transfocator	37.7	Beryllium lenses.	
Vertical slit	38.8	Defines horizontal secondary source when mirror is used.	
Secondary slits	48.4	Define footprint on monochromators.	OH4
Attenuators	48.8	Filter out low energies, especially when using DMM.	
DMM	49.8	Under design. Vertical deflection, beam offset 20 mm. Tentative specs: two strips $\text{Ru}/\text{B}_4\text{C}$, $\text{Ir}/\text{B}_4\text{C}$, $d = 2.4 \text{ nm}$. 400-mm substrates.	
DCM	52.7	Vertical deflection, beam offset 20 mm. $\text{Si}(111)$, LN_2 -cooled.	
EH3	from 165.7 to 174.1	Guard slits; TXM sample stage and zone-plate table; microtomography sample stage; detector table	EH3
EH4	from 197.2 to 208.5	Guard slits; microtomography sample stage; detector table; X-ray grating interferometer	EH4

long beamlines, *ANATOMIX* has its diaphragm defining the opening aperture of the beamline, a pair of primary slits and a *DiagOn* beam imager [22] using a silicon Bragg crystal.

A total-reflection double mirror M1–M2 (mechanics: IRELEC, Saint-Martin-d’Hères, France; optics: WinlightX, Pertuis, France) with a bender on the first substrate can be used to create a secondary horizontal source. The divergent beam downstream of the focus is up to 40 mm wide at the experiment position. On the other hand, for experiments requiring high intensity but not a large beam, an assembly of refractive X-ray lenses (a *transfocator*; following ESRF terminology for similar devices [23]) can be used to collimate the beam. Both mirror and transfocator are located in OH3, roughly 35 m from source.

A double-crystal monochromator (DCM) with $\text{Si}(111)$ Bragg crystals (AXILON AG, Cologne, Germany) and a double-multilayer monochromator (DMM) will be installed in the following optics hutch, OH4. The monochromators have vertical deflection geometry for an optimum match of the usable aperture to the beam dimensions and for minimum perturbation of the horizontal wavefront profile, as this is the in-plane direction for axial slices in tomography with a vertical rotation axis.

The X-ray flux density at the sample position using the DMM, without mirror or transfocator, is estimated to vary from more than $10^{12} \text{ ph}/(\text{mm}^2 \cdot \text{s})$ below 18 keV to roughly $10^{11} \text{ ph}/(\text{mm}^2 \cdot \text{s})$ at 25 keV. The DMM-beam flux at 18 keV will be around 10^{14} ph/s . Use of the mirror to obtain a wide beam reduces the flux density by about an order of magnitude; collimation with the transfocator, on the other hand, can increase it by a similar factor. The DCM will yield about $100\times$ less flux than the DMM; the correspondingly narrower energy bandwidth of the beam is necessary for the TXM.

The first of the two experimental hutches of *ANATOMIX*, EH3, will host the TXM sample stage and zone plates, a sample stage for parallel-beam microtomography and a detector table. The second

experiment hutch (EH4) will hold another microtomography sample stage and detector stage and a grating interferometer. It may also be used for a direct-detection pixel detector used with the TXM.

3. Current status and conclusion

ANATOMIX is currently under construction and expected to begin user operation in 2018. Since the final cryogenic U18 in-vacuum undulator [24] is still under construction, an in-vacuum U20 undulator is used for commissioning. The optical elements from the source to (and including) the mirror are operational or under commissioning; the other beam conditioning optics are ordered or under construction. The experimental stations are under construction and/or design. The first beam in experimental hutch EH3 was observed on 26 September 2016.

Acknowledgments

All support groups, the accelerator and source groups and the SOLEIL administration are gratefully acknowledged for their efforts for the *ANATOMIX* project. We thank A. King, J.-P. Itié and S. Schöder from the *PSICHÉ* and *PUMA* beamlines of SOLEIL for supplying data for Table 1.

The construction of *ANATOMIX* is largely funded by the French National Research Agency (ANR) through the EQUIPEX investment program, project *NanoimagesX*, grant no. ANR-11-EQPX-0031. The *NanoimagesX* consortium comprises 17 partner units from public research and industry. They are acknowledged for their contributions to the functional specifications of the experimental stations.

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