MHz - Tomoscopy

D1.3

Realisation of the mechatronics for the MHz-TOMOSCOPY prototype

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1 Design parameters of the Tomoscopy experimental setup

The MHz-TOMOSCOPY projects aims at determining structural changes to a sample in a time-resolved fashion using a series of high-intensity x-ray pulses coming from the European X-ray free electron laser in Hamburg in 3D. For this the extremely short femtosecond x-ray pulses coming from the accelerator are deflected at different angles using crystal monochromators, which allows to view the samples from different directions and thus gather 3D information from one single shot. For this, the monochromator crystals are arranged in such way, that the diffracted beams all overlap at the exact position of the sample. The X-rays transmitted trough the sample and carrying the structural information about the sample are then recorded with high-resolution X-ray microscopes (figure 1). In order to minimize intensity losses due to polarization effects of the incoming X-rays, it was decided to build the MHz-TOMOSCOPY setup in vertical diffraction geometry. The setup consists of a solid granite block as low vibration basis carrying the experimental setup, 6 crystal monochromator units for deflecting the X-ray at different angles, 2 motorized sample stages carrying the different sample environments, and the 6 high-resolution X-ray microscopes, which are mounted in a staggered configuration on 2 vertical high-precision arc segments.

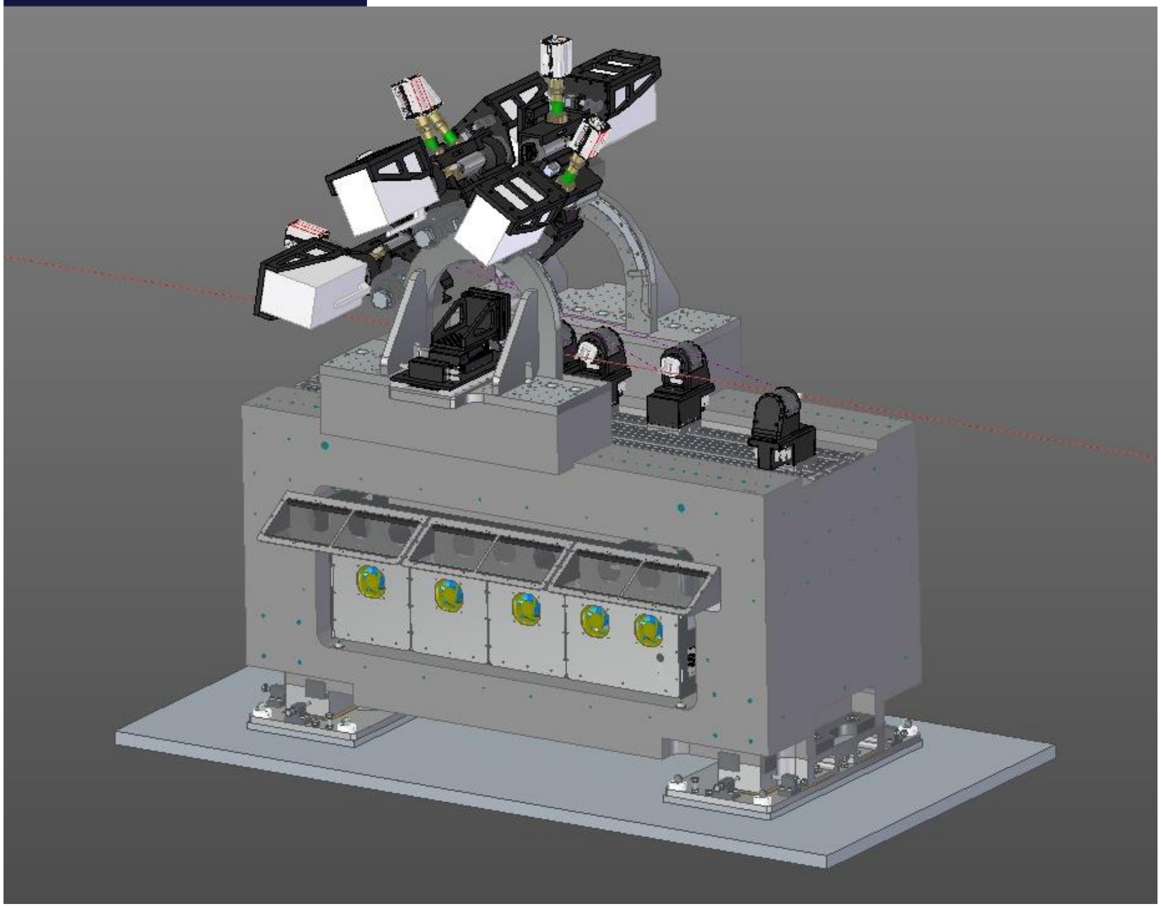

Figure 1: Schematic drawing of the Tomoscopy setup showing all components. The path of the different X-ray beams is indicated in pink.

2 Technical Implementation

2.1 Granite support

The entire experimental setup is mounted on a massive granite support (figure 2). The granite block is mounted on a support structure, allowing precise alignment of the granite block with respect to the incident X-ray beam direction. The top side of the granite is equipped with two rail systems. Each rail is equipped with three carriages for carrying the crystal monochromator units. both the sides of the granite block are further equipped with two smaller granite blocks, which serve as support structure for the two arc-segments, carrying the high-resolution X-ray microscopes. The granite is equipped with several internal holes and channels for efficient internal cable managements.

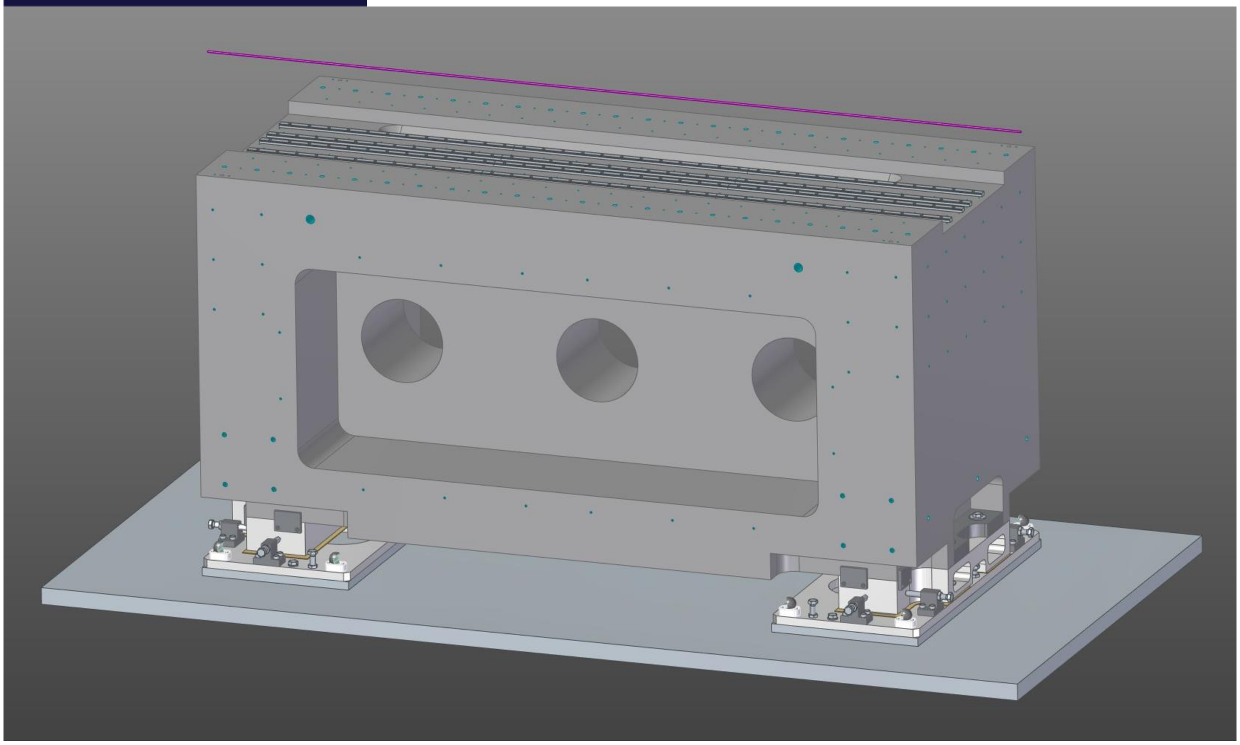

Figure 2: A massive Granite block serves a robust support for the Tomoscopy experiment. A support structure below allows precise alignment of the granite with respect to the incident beam direction.

2.2 Crystal monochromator positioning units

The setup comprises up to 6 crystal monochromator units (figure 3). Each of these units is mounted on the rail system on top of the granite block. The rail system allows coarse positioning and fixation of the monochromator units along the X-ray beam direction. Each of the units provides 6 degrees of freedom:3 translational degrees of freedom in x,y,z with travel ranges of each 10mm for fine positioning of the monochromator crystals in the X-ray beam, one rotational degree of freedom (theta) for adjusting the Bragg angle, and pitch and yaw for angular alignment of the monochromator crystals with respect to the theta rotation axis. All stages are operated with stepper motor, except the theta rotation which is operated with a directly driven servo motor in closed loop operation with an encoder system.

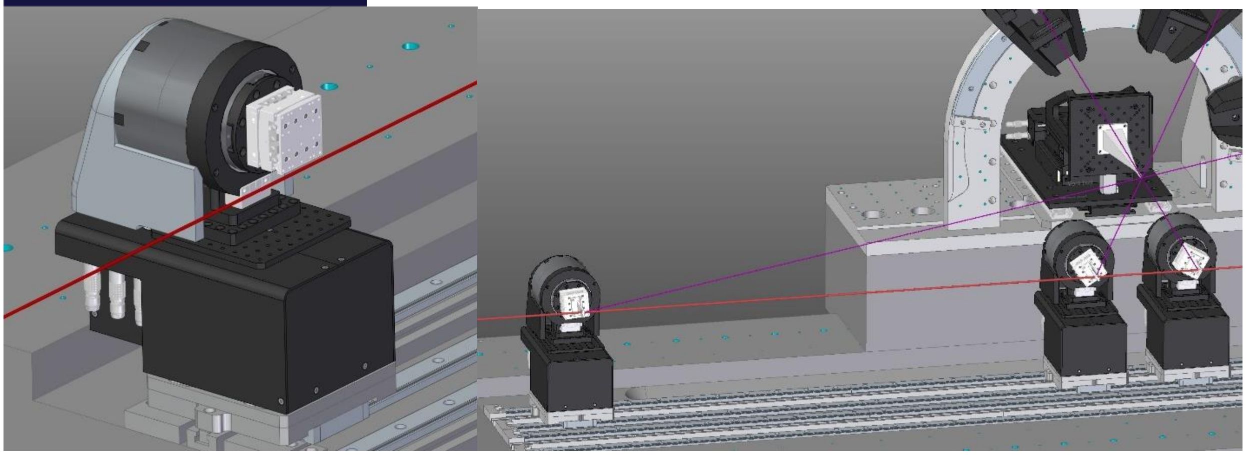

Figure 3: Crystal monochromator positioning units mounted on the granites rail system for coarse positioning along the incident X-ray beam and providing 6 degrees of motional freedom for precise positioning and alignment of the crystal monochromators.

2.3 Sample positioning units

The setup is equipped with two sample positioning units, which are mounted on top of the two smaller granite blocks carrying the arc segments (figure 4). The sample positioning units allow motorized alignment of different sample environments with a total weight of up to 10 kg with micrometer precision in all 3 directions (x,y,z) Travel ranges in all three directions are +/- 10 mm. For easy access and exchange of the sample environments the entire unit can be pulled out 50 cm from the interaction point with a kind of drawer. In this position good access to the sample environment is possible.

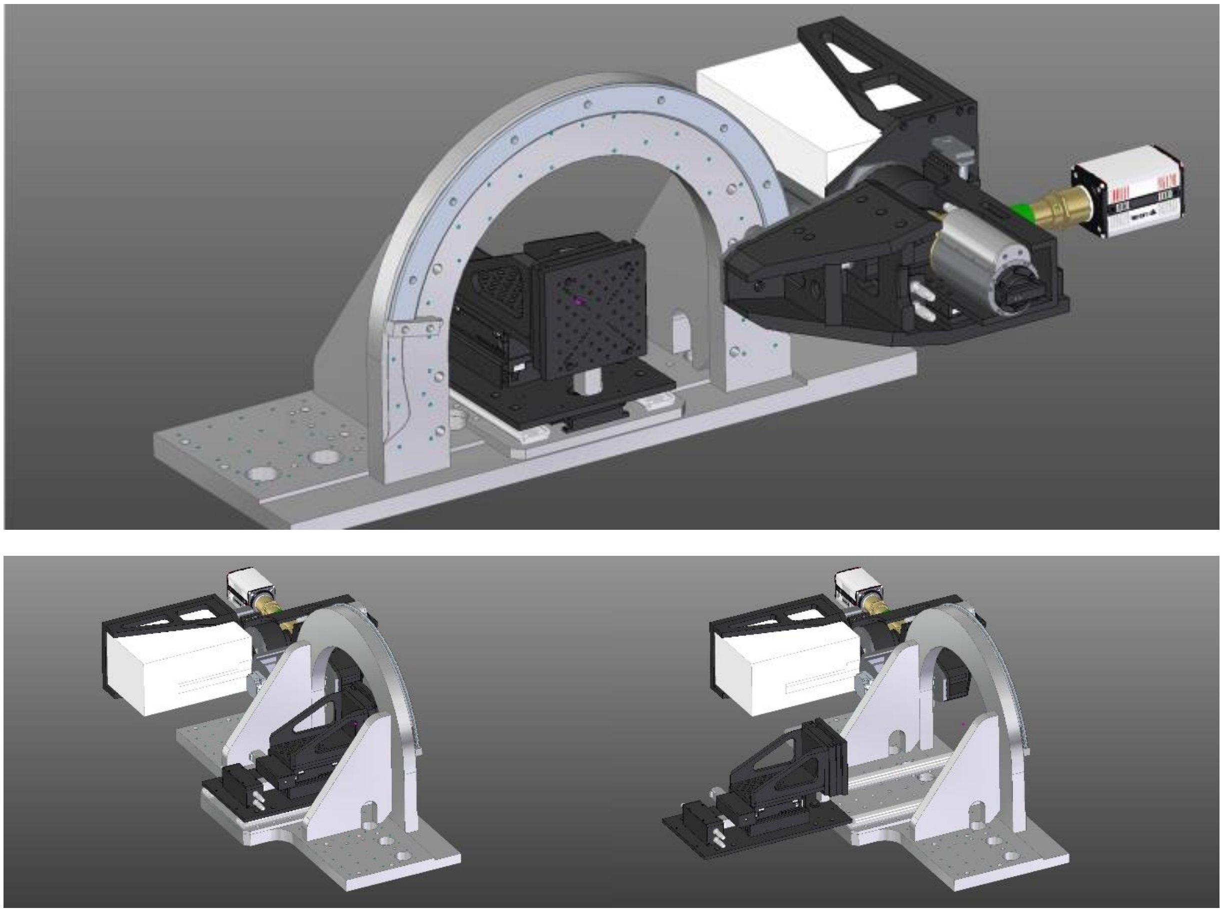

Figure 4: One of the two sample positioning units providing three translational degrees of freedom with micrometer position (top). For easy access to sample environment, the setup can be pulled out with a kind of drawer. ‘in’-position (bottom left, ‘out-position (bottom right)

2.4 Arc-segments with motorized microscope positioners

The six high-resolution X-ray microscopes are mounted on two arc segments on both sides of the granite block. Each arc-segment can carry up to three high-resolution X-ray microscopes. The camera units are mounted on carriages in a staggered configuration, so that the minimal angular separation between two units is only 12°. Angular adjustment of the carriages on the arc segment is performed by stepper motors acting with a gearwheel on a corresponding tooth wreath of the arc-segment. An additional motorized translation stage allows for precise alignment of the camera in horizontal direction with a travel range of +/- 10 mm.

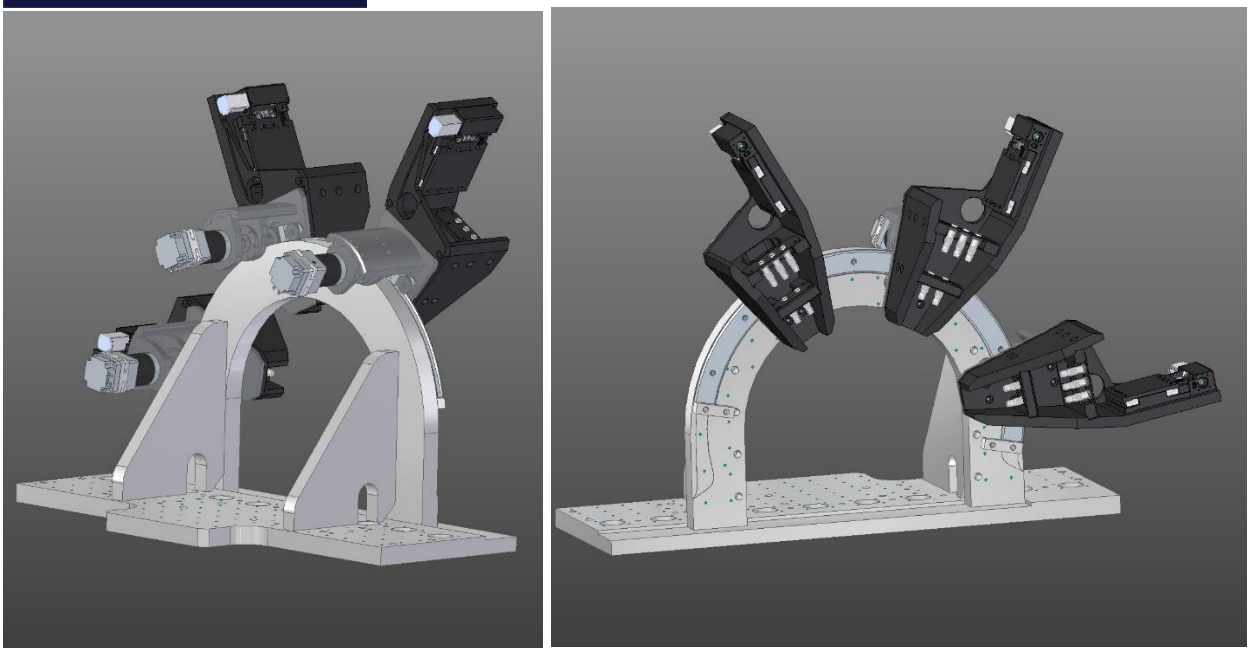

Figure 5: Motorized microscopes positioning units mounted on arc-segments for precise angular alignment.

2.5 High-resolution X-ray microscopes

The setup can be equipped with 6 high-resolution X-ray microscopes, which are mounted on the corresponding mounting units. Imaging of the X-ray beam is realized using X-ray luminescence in the VIS range coming from a scintillator screen. The luminescence light is deflected by 90 degrees with a mirror before it is collected by a microscope objective. Focusing of the images is achieved by motorized precise movement of the microscope objective along its optical axis. Behind the microscope objective the microscope image is either imaged in straight geometry on a high-speed Shimadzu CCD camera or a deflecting mirror can be inserted into the beam path to deflect the image by 90 degrees and guide it to a second C-mount CCD camera. It is further possible, to rotate the Shimadzu cameras by +/- 2.5 degree along the optical axis for better alignment of the images recorded by the different Shimadzu CCD-cameras

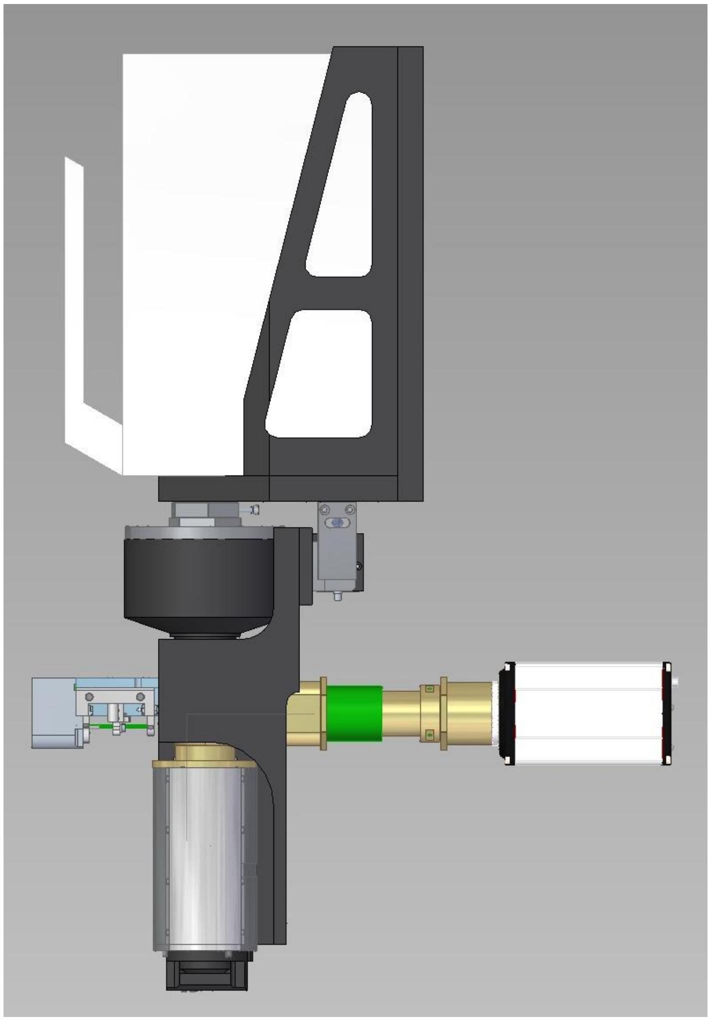

Figure 6: Scintillator-based high-resolution X-ray microscope unit for high-speed MHz imaging of X-rays. A motorized beam deflector allows to guide the microscope image either to the high-speed Shimadzu camera (top of the image) or a smaller CCD camera (right side of the image) for alignment purposes.

2.6 Motion controller

The setup is controlled by 8 x 8-channel stepper motor controllers and 1 x 8-channel servo motor controller for the theta rotation of the monochromator units. The device uses the Tango control system. The controllers are integrated into the granite block. A guided air flow avoids heat accumulation in the controller unit and therewith heating of entire granite potentially causing thermal drifts of the components. For local control the setup is further equipped with 6 touch screens providing access to all motors. For interfacing with the control system used by the facility a REST-API is available via Ethernet.

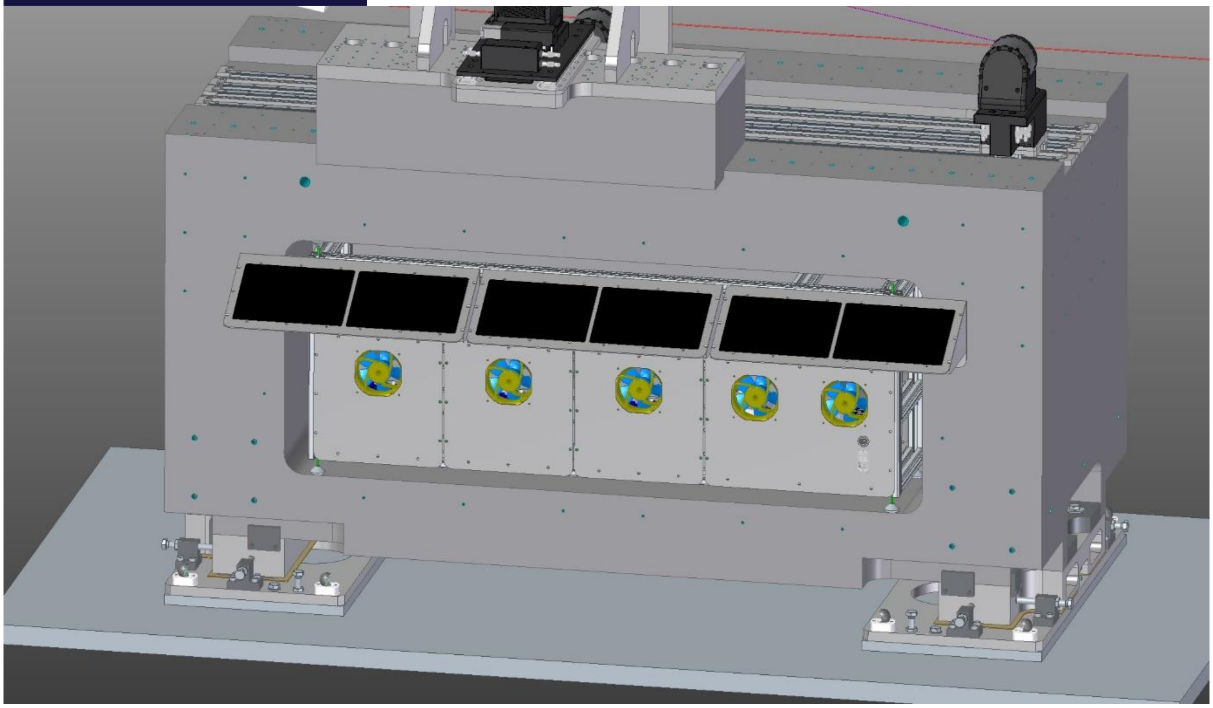

Figure 7: CAD-drawing of the motion controllers of the MHz-TOMOSCOPY project. The controller units are located in recesses in the granite block to save space. Touchscreens allow local control of the motor positions for adjustment pre-adjustment in addition to remote control.

3 Experimental characterization

First experimental characterization was performed in April 2024. Only one arm assembly was available which allowed to explore up to Diamond 400 reflection.

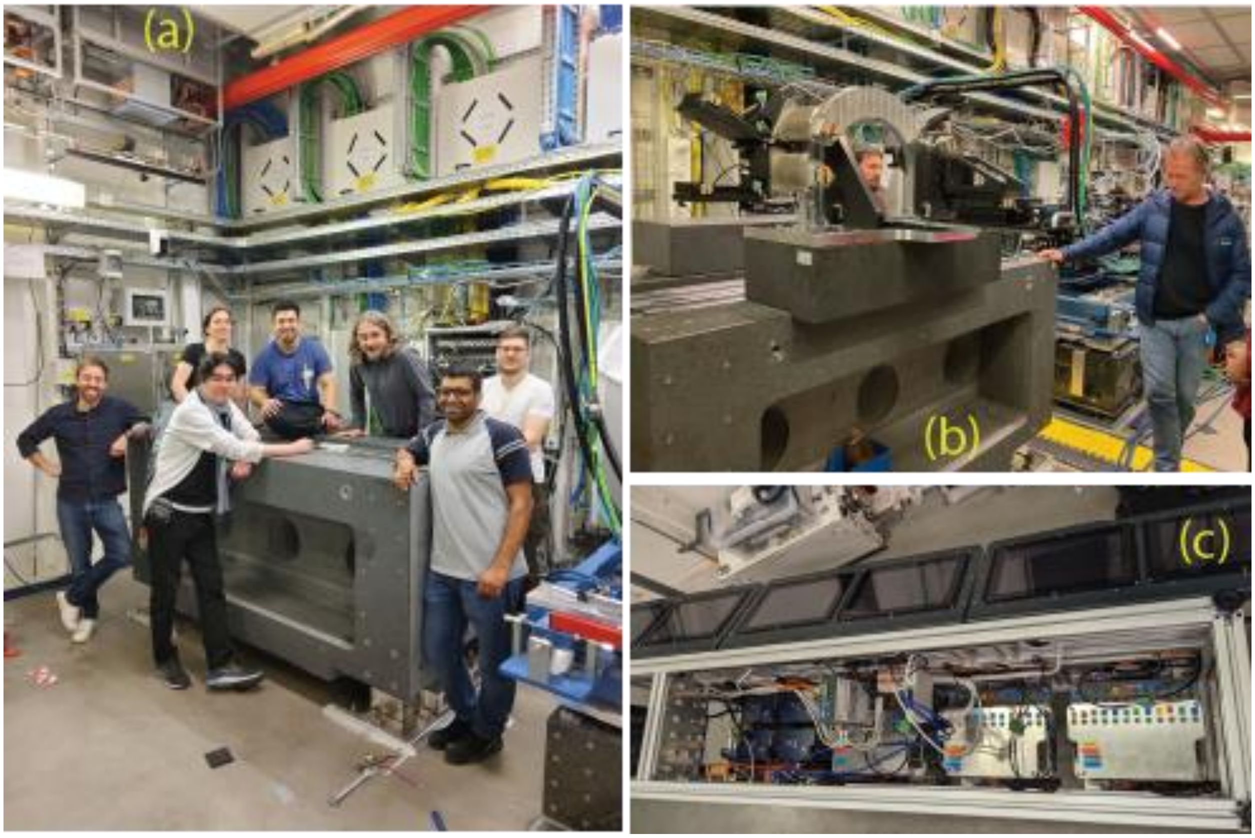

Figure 8. MHz-Tomoscopy prototype installation in April 2024.

Sample system developed at UOXF was successfully mounted and imaged with Diamond 220 Bragg reflection and Diamond 400 Bragg reflection providing enough intensity. Full assembly is being performed in November 2024 with four cameras and four crystals.

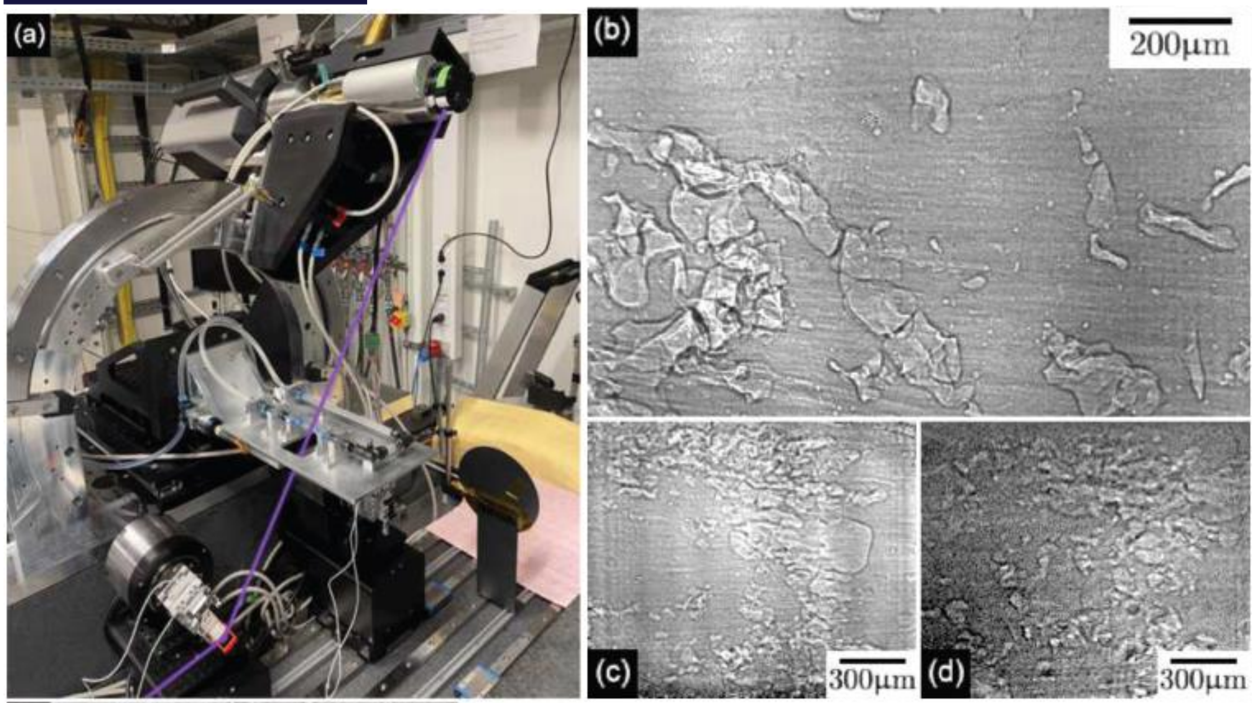

Figure 9. Realised one arm sigma polarization setup, image b is the direct beam X-ray image of the sample and c) is 220 Diamond beamlet imaging the sample and d) is 400 Diamond beamlet.

Data from last commissioning are under the evaluation but already demonstrates the feasibility of the method.