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HECTOR: A 240kV micro-CT setup optimized for research

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Abstract. X-ray micro-CT has become a very powerful and common tool for non-destructive three-dimensional (3D) visualization and analysis of objects. Many systems are commercially available, but they are typically limited in terms of operational freedom both from a mechanical point of view as well as for acquisition routines. HECTOR is the latest system developed by the Ghent University Centre for X-ray Tomography (http://www.ugct.ugent.be) in collaboration with X-Ray Engineering (XRE bvba, Ghent, Belgium). It consists of a mechanical setup with nine motorized axes and a modular acquisition software package and combines a microfocus directional target X-ray source up to 240 kV with a large flat-panel detector. Provisions are made to install a line-detector for a maximal operational range. The system can accommodate samples up to 80 kg, 1 m long and 80 cm in diameter while it is also suited for high resolution (down to 4 μm) tomography. The bi-directional detector tiling is suited for large samples while the variable source-detector distance optimizes the signal to noise ratio (SNR) for every type of sample, even with peripheral equipment such as compression stages or climate chambers. The large vertical travel of 1 m can be used for helical scanning and a vertical detector rotation axis allows laminography experiments.
The setup is installed in a large concrete bunker to allow accommodation of peripheral equipment such as pumps, chillers, etc., which can be integrated in the modular acquisition software to obtain a maximal correlation between the environmental control and the CT data taken. The acquisition software does not only allow good coupling with the peripheral equipment but its scripting feature is also particularly interesting for testing new and exotic acquisition routines.

1. Introduction

This paper presents the latest micro-CT scanner developed by UGCT, the Ghent University Centre for X-ray Tomography (http://www.ugct.ugent.be) in collaboration with X-Ray Engineering (XRE bvba, Ghent, Belgium). UGCT specializes in the development of micro-CT scanners which are aimed at pushing the boundaries of lab-based tomography, and at multidisciplinary research applications that require highly customized scanning conditions. To maximize the research possibilities UGCT designs and integrates its own scanners by acquiring the basic components and assembling them in room-size

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concrete bunkers. Each scanner is built in a modular way to allow for optimizations, modifications and improvements later on. The available scanners are used for fundamental research on the tomography technique itself as well as for multidisciplinary applications in collaboration with other researchers. CT research involves studying the physics behind tomography (X-ray production, X-ray interactions, phase contrast effects, etc), testing new technologies, optimizing acquisition protocols, programming reconstruction methods and 3D data analysis algorithms. Applied research covers a wide range of disciplines, and consequently a wide range of demands with regard to image resolution, field-of-view, acquisition time etc. The UGCT scanners that were available up to now already cover a wide range of applications. Spatial resolution of these previous scanners can go down to 400 nm, yet samples up to 35 cm in diameter can also be scanned, provided that there is sufficient transmission at the highest previously available tube voltage of 160 kVp.
However, the need was present to extend this range towards larger objects, more absorbing objects, and faster scanning. This resulted in the design of a new scanner, which focuses on this extended range without compromising but even improving the performance for traditional micro-CT.

2. Experimental setup

2.1. Hardware
One of the main components of the system is a XWT 240-SE microfocus source from X-RAY WorX. This high power reflection tube can deliver a target power of up to 280 W for high X-ray flux, while a minimum focal spot size of 4 µm makes the system useful for standard micro-CT scanning. A large 40x40 cm² PerkinElmer 1620 CN3 CS flat panel detector was chosen to allow for a large field-of-view. A rotation stage capable of handling heavy loads was mounted on a vertical stage with 1m travel to allow for helical scanning of long objects such as drill cores and wood logs.

A total of nine motorized stages ensures a high degree of geometrical flexibility. Next to the sample magnification stage to alter the source-to-object distance (SOD) and the sample vertical stage (along the rotation axis) for helical scanning and flat field positioning, the detector is mounted on a sytem of four motorized stages. A vertical and horizontal axis enables tiled radiography and extended tomography up to 4048 x 4048 pixels covering an area of 80 x 80 cm². Using the detector magnification stage, the source-to-detector distance (SDD) can be altered to optimize X-ray flux or cone angle. Furthermore, the detector is equipped with a laminography motor for future research. On top of the high-precision rotation stage, which nevertheless allows for a load of up to 80 kg, is a motorized XY stage to position the sample precisely on the rotation axis.

2.2. Software
To control the scanner, an in-house developed generic platform is used [1]. The platform is developed in LabVIEW and is used at all scanners available at UGCT. The separation between abstract operation of a generic CT scanner and the physical components of each different CT scanner makes the platform flexible and modular. New components can easily be implemented, while the main control software remains unchanged. The command-based operation makes it possible to implement additional devices (e.g. load cell) and include them into the CT scan using the scripting engine, which can be adapted to the specific scanner to include all available acquisition protocols such as step-and-shoot tomography, continuous rotation tomography, helical CT, tiled radiography and tomography, batch scanning, etc.

The tomographic reconstruction is performed using the in-house developed software package Octopus ([2], http://www.octopusreconstruction.com). Any geometrical misalignments of the scanner can automatically be corrected in the reconstruction core, resulting in optimal image quality.

3. Results

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Some results, which indicate the possibilities and strengths of the system, are listed in the section below.

3.1. Large object

A concrete drilling core with a diameter of 12 cm was scanned at a tube voltage of 230 kVp. A reconstructed slice is shown in figure 1. Although image contrast is rather low and beam hardening is still present, it must be kept in mind that we are dealing with concrete of 12 cm diameter, which is highly attenuating.

3.2. High resolution and phase-contrast radiography and tomography

Although the setup is designed to scan larger objects, standard micro-CT for smaller objects is still possible. This is illustrated in figure 2, where a reconstructed slice of a Bentheimer sandstone sample is shown. Using a source-to-object distance of 20.4 mm and a source-to-detector distance of 1000 mm, the effective isotropic reconstructed voxel size is 4^3 μm^3. Using the in-house developed image analysis software Morpho+ [3], the average grain size is determined to be 35.6^3 μm^3. Despite the small difference in attenuation coefficients, the distinction between the two phases, quartz and microcline, can be clearly made in the images.

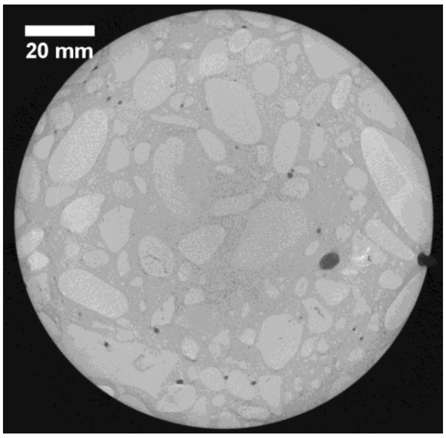

Figure 1. A reconstructed slice of a concrete core with a diameter of 12 cm

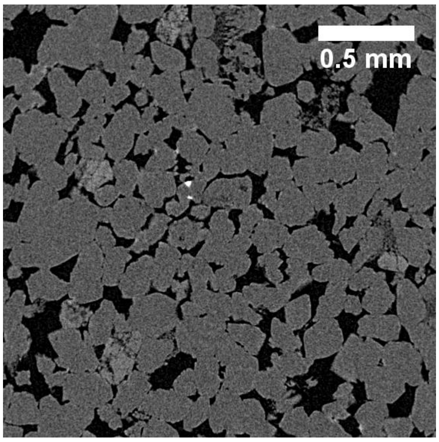

Figure 2. A region of interest from a reconstructed slice of a Bentheimer sandstone sample.

The large spatial coherence of the micro-focus X-ray source makes X-ray phase contrast imaging possible using in-line beam propagation. Since this method requires no additional hardware it can easily be performed, making use of the varying SDD up to 2000 mm. The use of special phase-retrieval algorithms improves significantly the signal-to-noise-ratio of the reconstructed data, making this technique very valuable for low-attenuating samples [4].

3.3. Flexible geometry

The trade-off between cone beam effect and image statistics is shown in figure 3. A bottle of water was scanned twice at an identical voxel size of 100^3 μm^3, but with a different SDD and corresponding SOD. This resulted in a cone angle of 13.24° for an SDD of 850 mm, and 6.01° for the SDD of 1900 mm. All other scanning parameters were kept constant (tube voltage 100 kVp, target power 50 W, 1200 projections at an exposure time of 1000 ms). Figure 3 shows a vertical cross-section through the complete object, where only the upper half is imaged (i.e. the bottom line is the vertical center). The cone effects can be clearly seen on the water surface and the top of figure 3 (left). In figure 3 (right), these effects have been largely reduced. On the other hand, X-ray flux is reduced by a factor 4 which results in lower statistics which can be observed in figure 3 (right). This is confirmed by the SNR measured on the water volume of the central slice, which is calculated to be 26.05 for the small SDD and 12.76 for the large SDD.

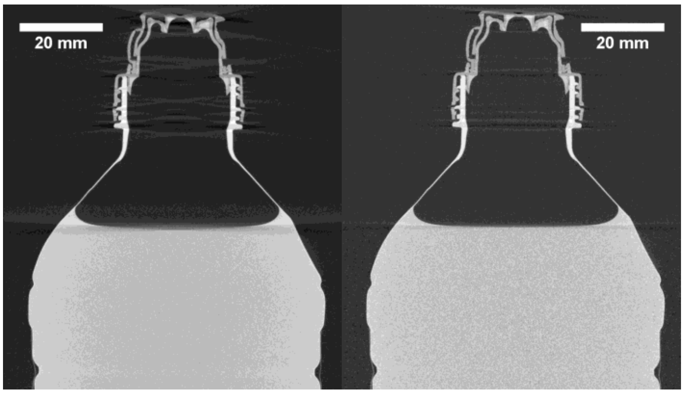

Figure 3. A bottle of water scanned at the same magnification but different source-to-detector distance (SDD).
Left: small SDD hence large cone angle and high flux
Right: large SDD hence small cone angle and low flux

4. Conclusion and outlook

A new 240 kVp setup is installed at UGCT and is now fully operational. The high X-ray energy and flux allow scanning larger samples with a higher content of high-Z material. Additionally, the scanner is capable of performing high-resolution scans down to 4 µm and phase-contrast imaging due to the high spatial coherence of the source.

The scanner is designed to be very flexible using a total of nine motorized stages. At the detector side, these motorized stages can also be used to switch between different detectors. To gain optimal performance from the high energy X-ray tube, a line detector is planned to be installed in the near future.

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