NEWSLETTER SPRING 2021

It is a pleasure for me to introduce to you a new issue of the newsletter of our Laboratory of X-ray micro and nano computed tomography at CEITEC BUT. You can read here about some of our recent analyses, including a dimensional analysis of high-attenuating samples or a visualization of wood anatomy with submicron resolution. We will describe dual-energy computerized tomography and the effect of different CT targets on imaging of low contrast biological samples and share some of the latest news, such as correlative imaging and detector upgrade.

Enjoy reading!

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Head of the laboratory

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DIMENSIONAL ANALYSIS OF HIGH-ATTENUATING SAMPLES

The application of X-ray computed tomography in dimensional metrology has several advantages over conventional techniques; primarily there is a possibility of inner features analysis without destruction or disassembly of the part. The main limit is, however, the ability of X-ray radiation to penetrate the samples. The most problematic are high-alloy steels or superalloys like Inconel®. Insufficient transmission of X-rays may cause image artifacts which increase the uncertainty of dimensional measurements. To evaluate this influence factor, we designed a stepped cylinder made of stainless steel. (Fig. 1). It allows us to analyze the inner diameters and determin the measurement uncertainty dependence on the cumulative thickness of the material transmitted by X-rays (10 mm, 20 mm, and 30 mm). The sample was scanned with an X-ray tube voltage of 200 kV and voxel resolution of 40 µm.

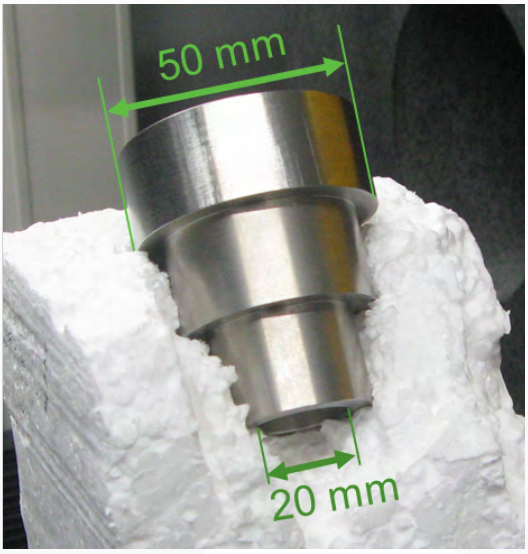

Figure 1: Stainless steel stepped cylinder fixed in microCT device.

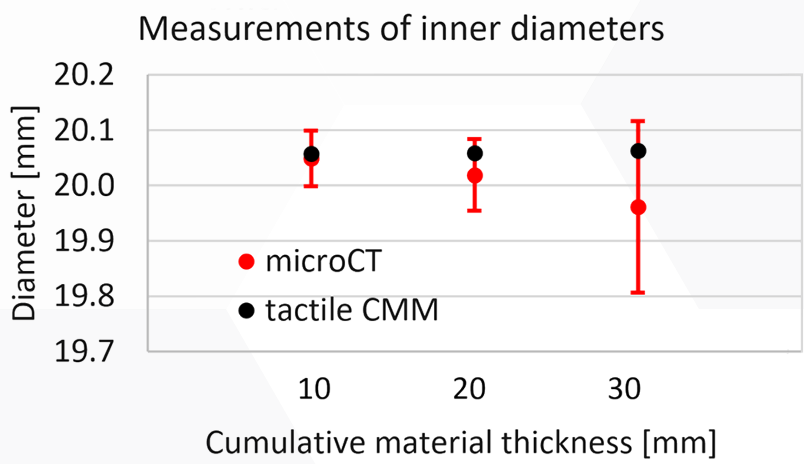

Chart 1. Results of inner diameter measurement on microCT data. Errors bars show measurement uncertainty, which is the highest in regions with largest cumulative thickness of material. For comparison is, the measurement using tactile coordinate measuring machine is shown.

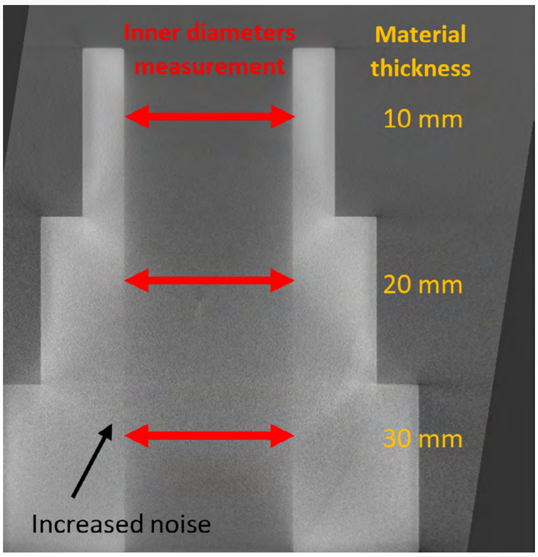

Figure 2: Tomographic cross-section, positions of inner diameter measurements are highlighted.

We have found out, that regions with the highest cumulative thickness of material suffers from increased noise, which makes it difficult to correctly determine the material interface (Fig. 2). In the case of such a quality decrease in the results of CT measurement, the uncertainty of diameter measurement may correspond to multiples of voxel size (here for inner diameters 50–150 µm, see Chart 1.) The uncertainty of measurement in regions with a lower material thickness where no significant image artifacts appear may reach less than one voxel size.

VISUALIZATION OF WOOD ANATOMY WITH SUBMICRON RESOLUTION

Wood is general composed of different types of cells and tissues, the arrangement of which depends on the environment. Trees can therefore be considered as sensors of their surroundings, when they react to changing temperatures and precipitation, while this information is then archived in the structure of the wood. Thus, if we could read this archived information from the anatomy of wood, it would be possible to determine how trees respond to the changing climate, as well as to study and evaluate the overall resilience of the forest. This is the goal of the scientific discipline of dendrochronology, which is being developed by the University of Ghent and specifically the UGent-Woodlab laboratory (www.woodlab.be). In cooperation with this laboratory for wood technology research, our laboratory tested the possibilities of the Rigaku nano3DX device for imaging the anatomy of wood with submicron resolution.

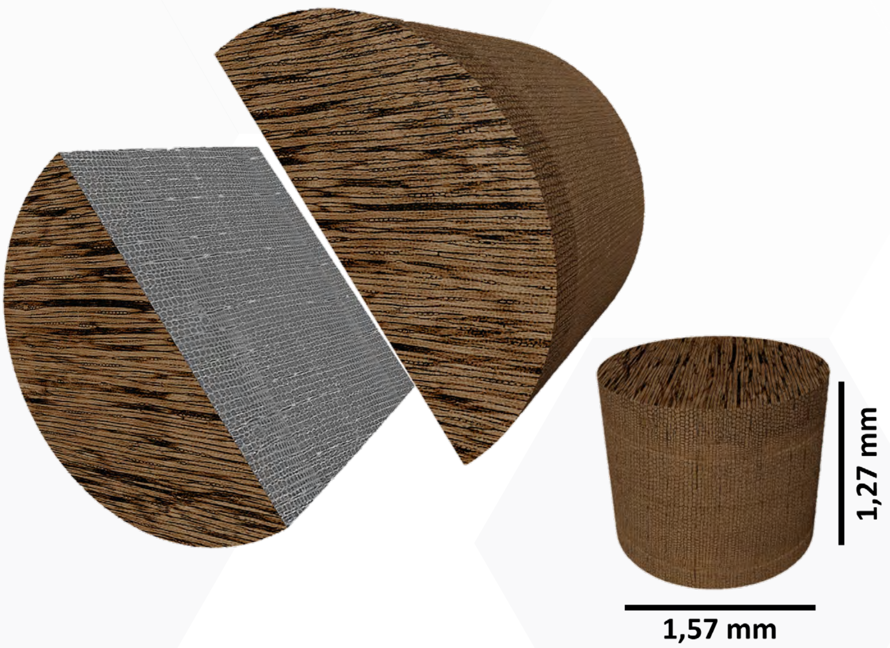

Figure 3: 3D wood model and virtual CT slice thought its internal structure.

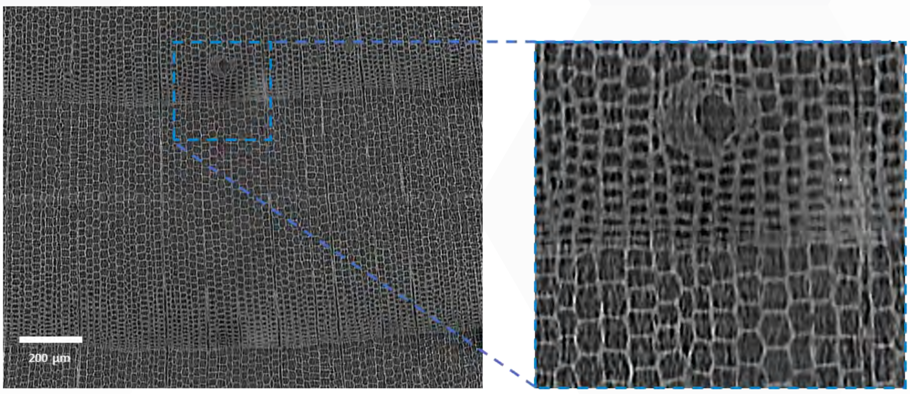

Figure 4: Sagittal CT slice though measured wood sample.

Within the conducted experiment, a sample of softwood, which was obtained using an incremental borer, was examined. To achieve the required submicron resolution and at the same time measure a sufficiently large area of interest, it was necessary to use a combination of off-set reconstruction (enlarging the field of view in the horizontal direction) and combining volumes of CT data (enlarging the field of view in the vertical direction). Using this special acquisition strategy, it was possible to measure a sample area of 1.57 mm x 1.27 mm (about 41 GB of data) at a linear voxel size of 0.52 µm.

On the resulting CT images, it was possible to distinguish growth rings as well as individual latewood and earlywood cells, and a resin duct. This type of scanning allows for highly detailed analysis (e.g. measuring of ring widths, cell counting) of a region of interest of an increment core, without subsampling.

DUAL - ENERGY COMPUTERIZED TOMOGRAPHY

In the last issue, we reported on the upgraded X-ray source of our nano-CT, the Rigaku nano3DX. The new source sports two anode targets made of different materials, and allows for dual-energy CT (DECT) measurements. The popularity of DECT has been rising in recent years, as the method broadens the possibilities of nondestructive sample analysis in a major way.
The first step of DECT is to perform two measurements of the same sample using two different X-ray energy spectra. (Figure 5). This can be done in various ways; in the nano3DX, there are two separate consecutive measurements, and a switch of the target material (and the X-ray spectrum) in between. Knowledge of the physical principles of X-rays and properties of the sample then allows us to extract information about materials inside the measured object, correct measurement errors, and create otherwise hard to achieve visualizations.

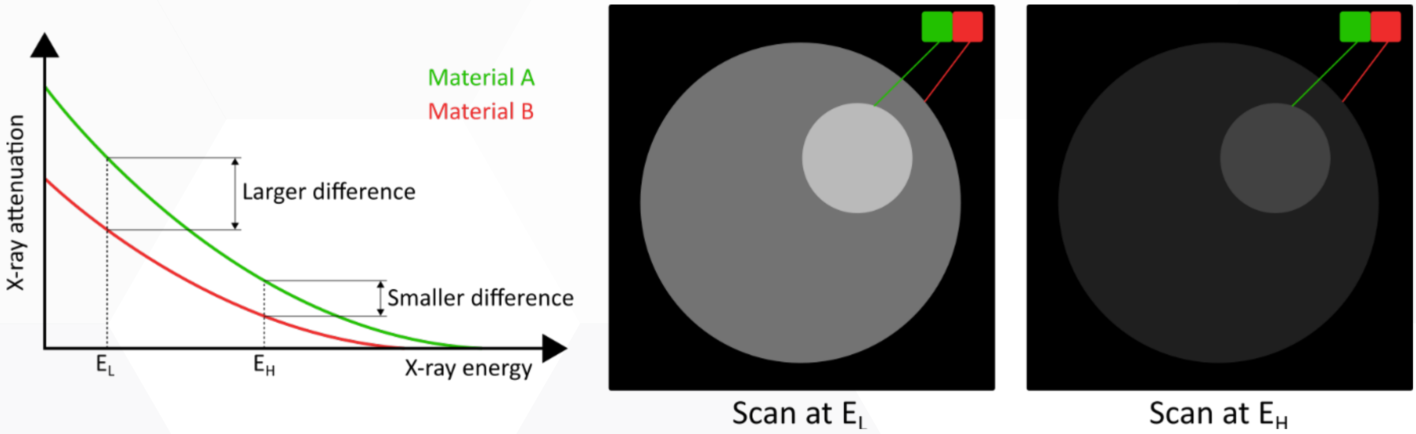

Figure 5: The graph on the left shows the dependence of X-ray attenuation in two different materials on X-ray energy. The middle image is a tomographic slice acquired using a lower energy EL, with high contrast between the two materials. If a higher energy EH is used (as in the image on the right), the difference in attenuation is less pronounced. This is the basis of DECT. Most real CT scanners do not actually use a single X-ray energy, but rather a spectrum of energies. Nevertheless, the principle of DECT remains the same.

DECT is frequently used to create so-called virtual monoenergetic images. Conventional CT uses a wide spectrum of X-ray energies, which leads to characteristic artifacts in tomographic slices, such as streaks and fluctuations of gray values in places, which are actually constant. These artifacts are effectively reduced in monoenergetic images, increasing image contrast. This is great for industrial applications, where these artifacts are common and prominent.

A second common DECT application is the decomposition of a sample into a basis pair of materials. All parts of the sample can be expressed as a mixture of two known materials, which makes it possible to characterize the materials of the sample based on how they appear in the chosen basis pair. Material decomposition is typically used to reliably remove certain objects from CT slices based on their material, which makes further analysis easier. In medicine, material decomposition can be used to remove calcified plaques in CT data of blood vessels, making possible a more accurate assessment of stenoses (pathological narrowing of blood vessels).

EFFECT OF DIFFERENT CT TARGETS ON IMAGING OF LOW CONTRAST BIOLOGICAL SAMPLES

The material of an X-ray tube anode (“target“) can modify the detection capabilities of a CT system because they produce a different X-ray spectra. The industrial CT systems are predominantly using a tungsten target for analysis of a metal samples. On the other hand the molybdenum target can be utilised for the lighter materials and biological tissues defined by low absorption.

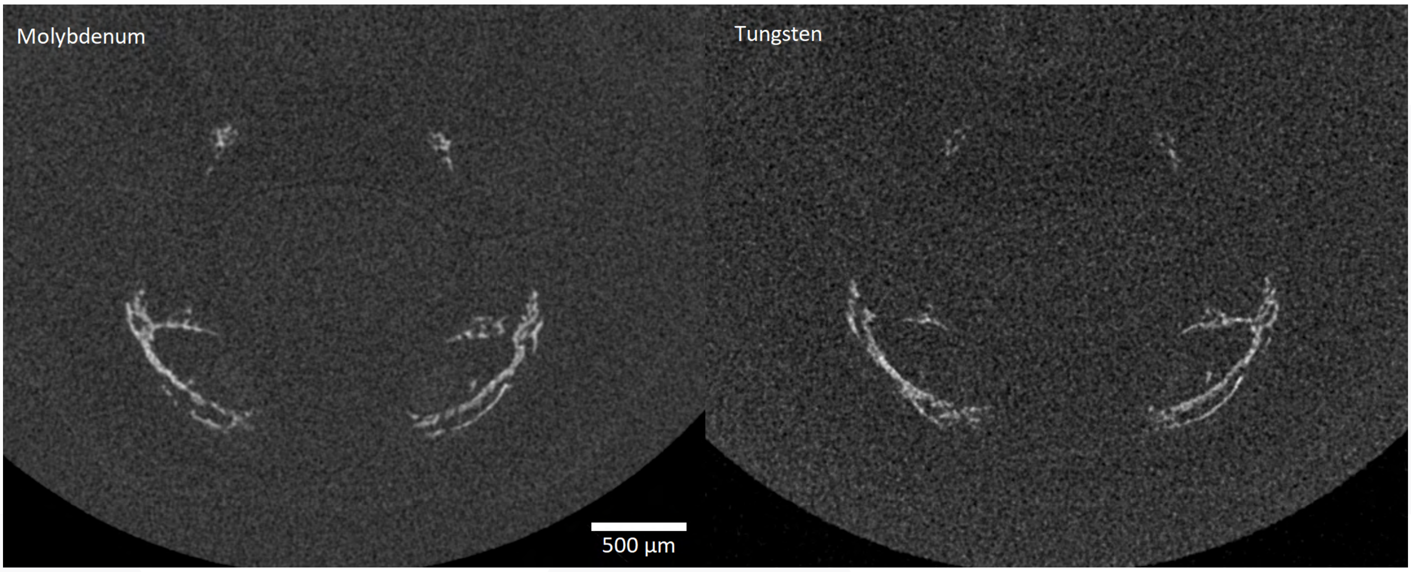

Figure 6: Figure 6: Comparison of CT sections through head of mouse embryo showing the ossifying bones: (a) molybdenum anode (SNR 6,74 a CNR 7,05) shows less noise than (b) tungsten one (SNR 4,33 a CNR 3,78).

The differences are shown on an image of newly developing bone tissue in 15-days-old mouse embryo. In all mammals the bones are created by gradual mineralization of cartilage during the embryonal development by the process called ossification, on the 15th day of mouse embryonal development the process of ossification is slowly starting and the mineralised “bones“ are still very delicate. The comparison of both CT scans using different targets shows improved signal (SNR) and contrast (CNR) in the molybdenum target (see Fig. 6). Furthermore, the reconstruction of the 3D model of bones showed better visualization of details in ossification clusters (Fig. 7) and manifested in calculation of total volume of the bone.

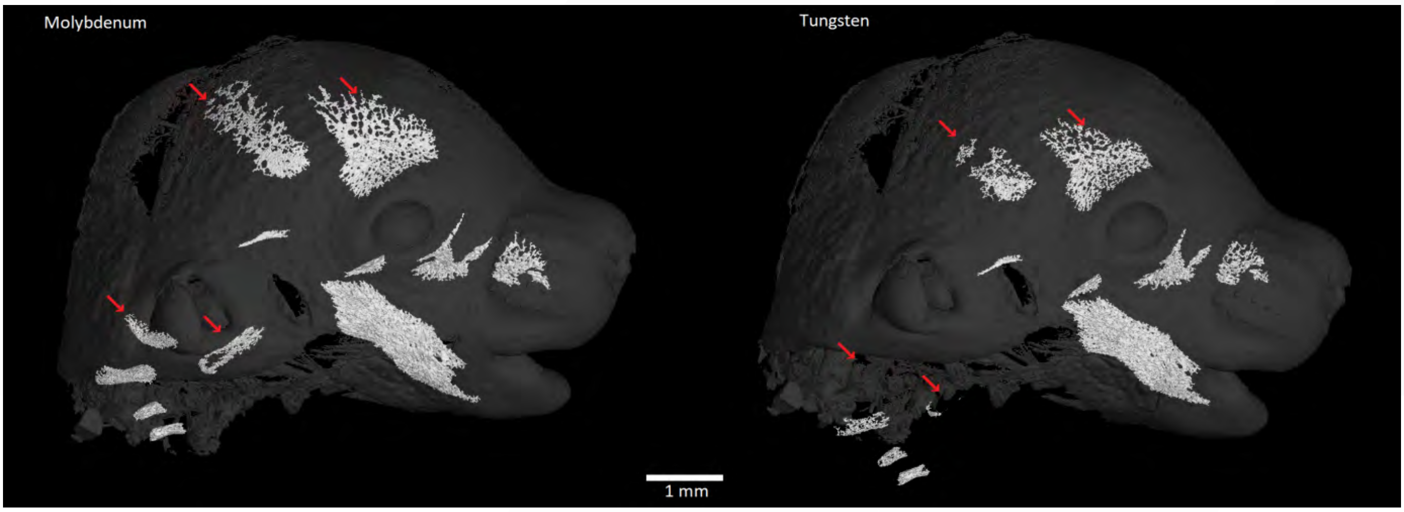

Figure 7: 3D reconstruction of ossified bones with total bone volume of (a) 0.19 mm3 in molybdenum target and (b) 0.12 mm3 in tungsten target. The red arrows are pointing out the differences in detection.

CORRELATIVE IMAGING

The registration of two or more images from different imaging modalities is called correlation microscopy. It allows to connect the information from different imaging techniques or information from the same modalities at different scales to obtain the same areas. The object and result of such a combination are to create completely new information that can be used to evaluate and characterize materials. The latest challenge is to combine 2D images from electron microscopy (EM), for example, with 3D X-ray computed tomography (CT) images. CT plays the role of a non-destructive tool for selecting a suitable area and navigating for additional sample surface preparation. The whole procedure begins with a non-destructive CT measurement of the sample. In the following step, an electron image is acquired for the sample surface, registered with CT data. After registration, the user labels the area of interest in the internal structure found in the CT data. This area is then dugout with an ion beam, and the EM section is scanned section by section. It results in a series of 2D images with high resolution or chemical composition in using EDX.

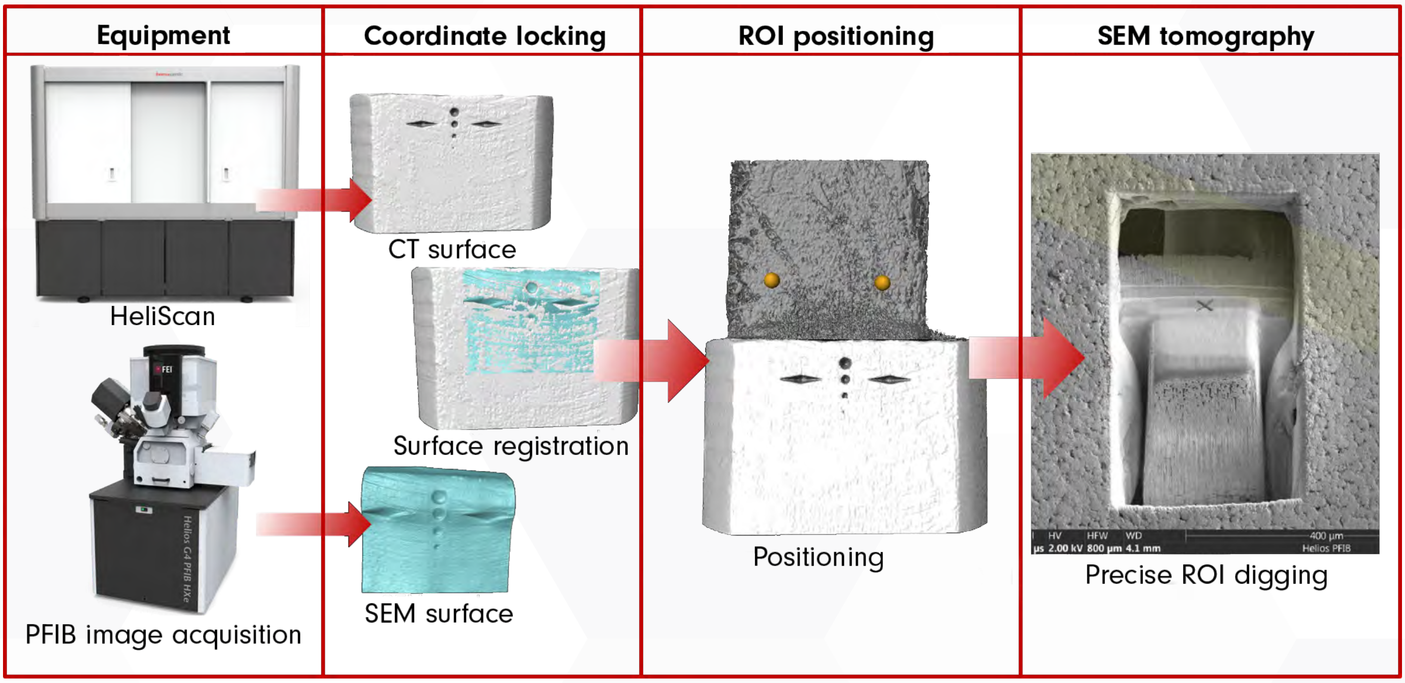

Figure 8: Correlation imaging procedure.

Our laboratory is involved in developing a new module that would automatically perform this multi-modal and multi-scale data correlation. The presented module is created in cooperation with Avizo software (Thermo Fisher Scientific). The workflow is based on CT and EM data registration using reference marks on a unique sample holder, compatible with both instruments. This module is in the last phase of testing, and we can expect its launch soon.

DETECTOR UPGRADE

Since we are part of the Central European Institute of Technology, it is essential to keep our equipment up to date. Thus, we upgraded the detector in our CT machine GE phoenix v|tome|x M300 in the fall of 2020. The original detector DXR250 Digital has been replaced by a new detector Dynamic 41|200. This new detector (The Dynamic 41|200 detector) works at 410 x 410 mm² detection area with 200 microns pixel size. In comparison to the old DXR250 Digital, the new detector is enhanced by higher sensitivity. That could be used for heavy materials which are hard to penetrade. Furthermore, the detection speed is improved which could lower the scanning time almost twice in some cases.

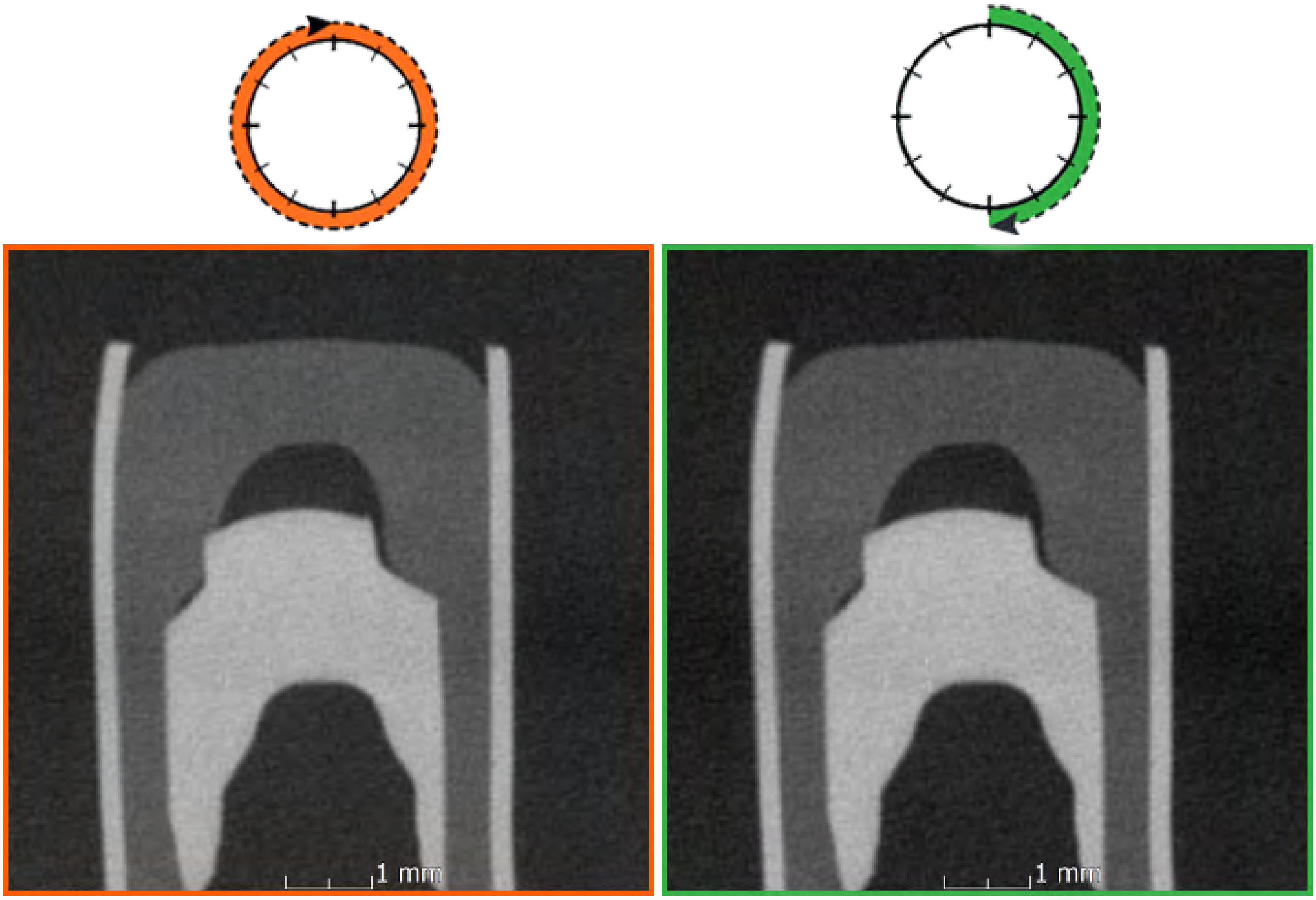

Figure 10: Comparison of two tomographic cross-sections showing the automotive part assembled from plastic and alluminium. Orange (left) – CT data obtained from the old detector. Green (right) – CT data obtained from the new detector at half of the scanning time.

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