Determination of measurement uncertainties of holes in steel components by X-ray computed tomography

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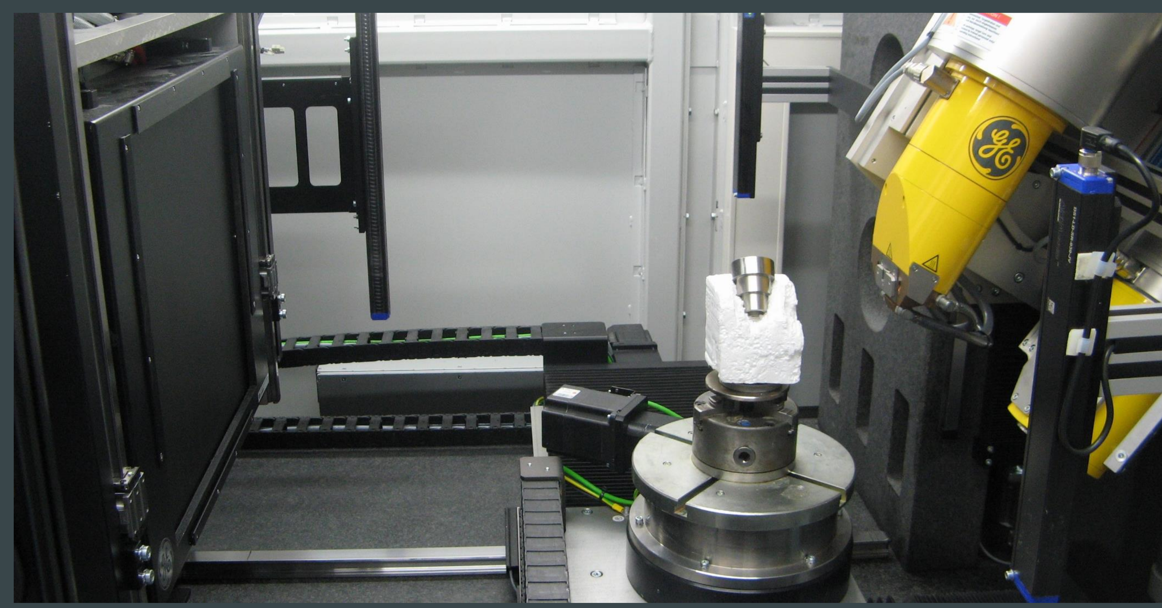
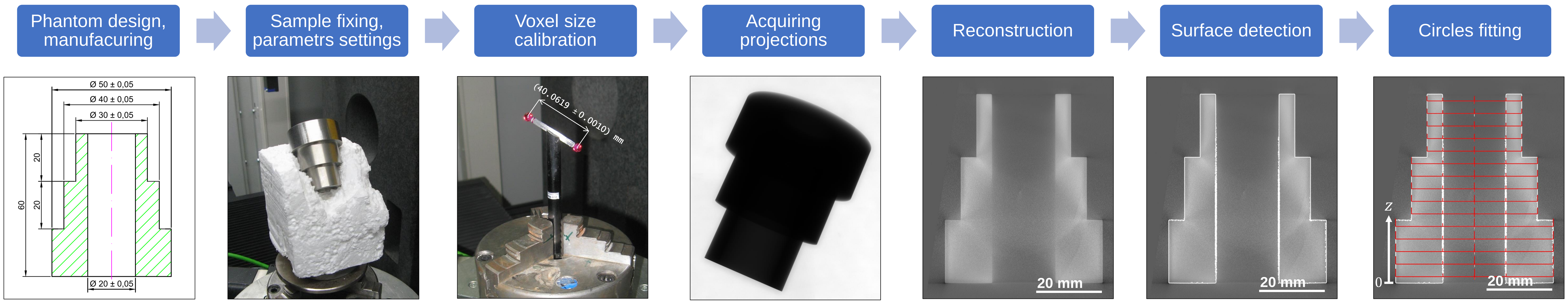
Abstract

Due to the complexity of CT measurement, uncertainties determination can be a complicated process. The aim of this work is to experimentally determine the uncertainty of tomographic measurement of holes diameters in a selected workpiece on a CT device GE phoenix v|tome|x L240. The workpiece was designed in order to find variations of uncertainty depending on material penetration length.

The uncertainty was determined according to VDI/VDE 2630/2.1. The reference measurement was performed on length measuring machine SIP 1002 M. Consequently, several measurements with the same settings were performed on the GE phoenix v|tome|x L240 microCT device. The uncertainties of inner and outer circular diameters were calculated for two settings of surface determination.



CT measurement workflow:



Methodology

Determining uncertainty according to VDI/VDE 2630/2.1. consists of several steps:

1. Reference measurement of the geometric features of the sample, usually on tactile CMM.
2. CT measurements, the VDI/VDE 2630/2.1.[1] requires at least 20 measurement with the same settings for statistically sufficient amount of data.
3. Evaluation of the components of measurement uncertainty
4. Calculation of expanded uncertainty U.

The expanded uncertainty of measurement without correction of systematic error is calculated as

$$U = k \cdot \sqrt{u_{\mathrm{cal}}^2 + u_p^2 + u_w^2 + b^2}\,.$$

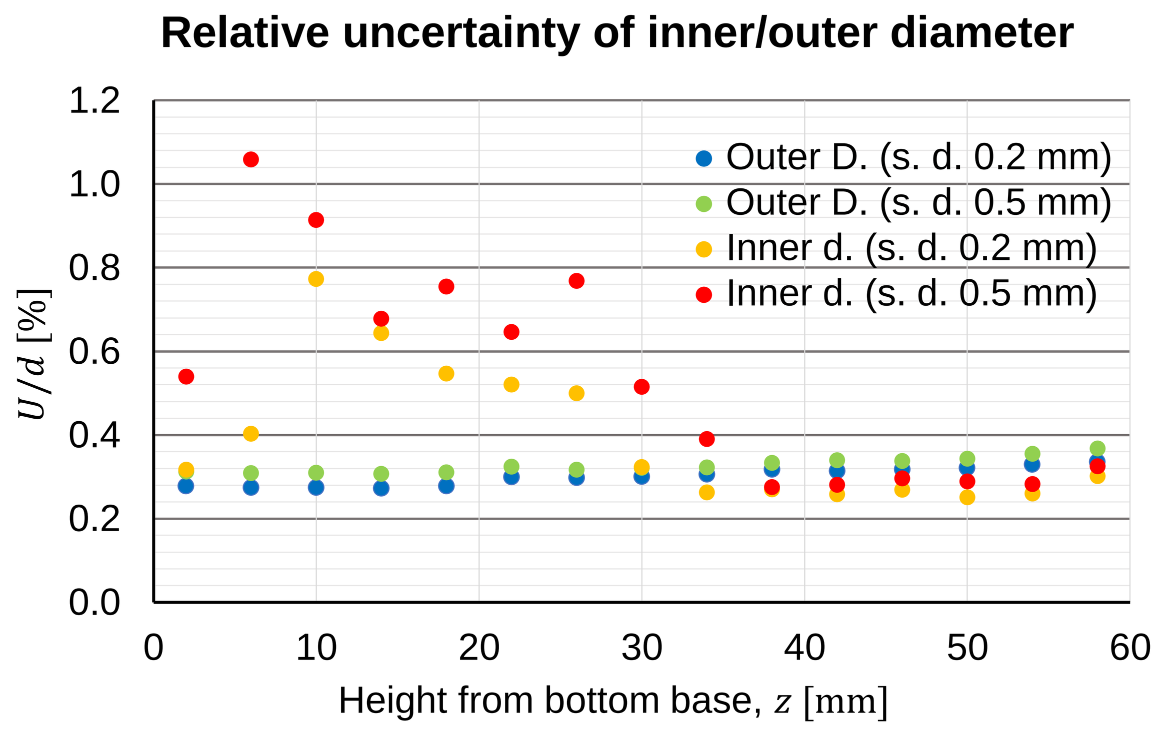
Coverage factor $k = 2$ corresponds to 95% coverage interval. The components of the uncertainty are

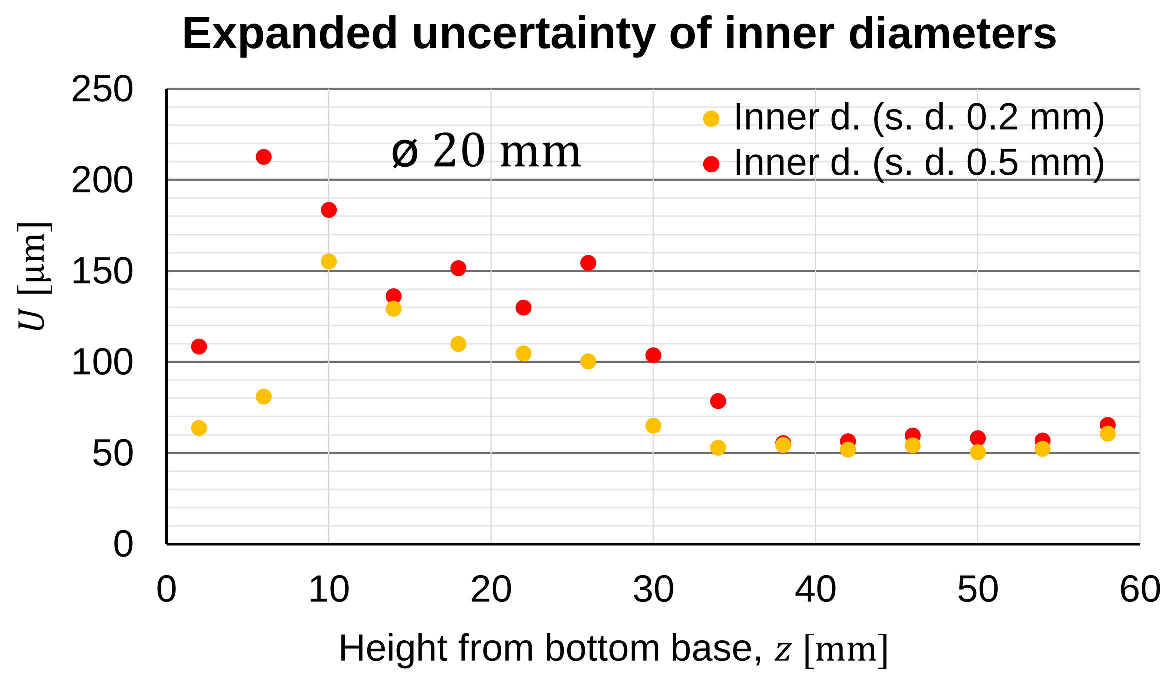
- u_{cal} – standard uncertainty associated with the uncertainty of the calibration of the calibrated workpiece stated in the calibration certificate
- u_{p} – standard uncertainty associated with the measurement procedure, $u_{\mathrm{p}} = \sqrt{\frac{1}{n-1}(y_i - \bar{y})^2}$. Acquiring required amount of measurements (20) could be very time and finance consuming. The safety factor h can be used [2,3] and u_p is calculated as $u_{\mathrm{p}} = h\sqrt{\frac{1}{n-1}(y_i - \bar{y})^2}$
- u_{w} – standard uncertainty associated with material and manufacturing variations (thermal expansion, roughness), $u_{\mathrm{w}} = \sqrt{u_{\mathrm{T}}^2 + u_{\mathrm{R}}^2}$.
- b – systematic error, $b = \bar{y} - x_{\mathrm{cal}}$.

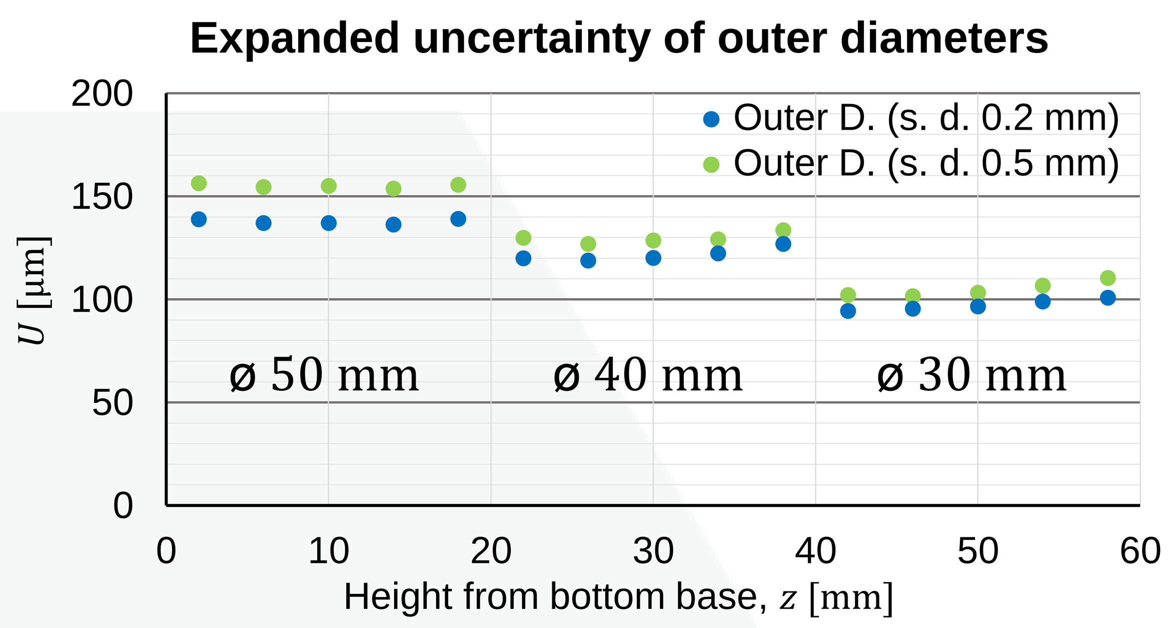
Measurement

A hollow stainless steel stepped cylinder was manufactured in order to find a dependence of measurement uncertainties of inner and outer diameters on the cross-sectional material thickness. The cylinder is made of stainless steel DIN 1.4305 (BSI 303S21).

The reference measurement of inner and outer diameters was performed on length measuring machine SIP 1002 M. The expanded uncertainty is $U = 0.0020$ mm.







CT measurement parameters:

Voltage	Current	Exposure time	Numb. of images	Filter	Voxel size
200 kV	240 μm	600 ms	2000	0.5 mm Sn, 0.5 mm Cu	40 μm

The laboratory at CEITEC was accredited according to CSN EN ISO/IEC 17025. The measurement was performed according to approved methodic. Position of the sample is shown in the image of projection acquisition. Due to the high time and financial demands of CT measurements, only 7 measurement on CT were performed. The data were processed in VGStudio MAX 3.1. The surface was detected using CAD model as starting contour, two search distances (0.5 and 0.2 mm) were used. The uncertainty u_{p} was calculated using coefficient $h = 1.3$.

Results

Expanded uncertainties of measured diameters are shown in charts. The highest diameter uncertainty is of the inner circles positioned in the bottom part of the sample. There is the highest amount of noise, caused by high attenuation of X-rays and scattering. The noise is not distributed uniformly in the bottom part, because the sample was tilted to eliminate cone beam artifacts.

The uncertainty of outer circles shows less affection by the thickness of the material. It slightly increases with the distance from bottom base.

Conclusion

The uncertainty of inner diameters increases (from 50 μm up to 210 μm) with material penetration length.

The other approaches like simulations and analysis of model function are problematic, because all factors influencing CT measurement and their exact effect are not known [4]. The experimental method therefore can provide most relevant results for specific sample. The results can be carefully generalized for similar measurements, however the attention should be focused on the fact that sample itself (material, shape, size) has large influence on the measurement. Also the acquisition of statistically sufficient amount of data is usually problematic due to the high time and financial costs of measurement.

Acknowledgements

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