

# Influence of Continuous Scan Mode and Workpiece Positioning on Dimensional Measurements with Computed Tomography

*Christian Orgeldinger<sup>1</sup>, Florian Wohlgemuth<sup>1</sup>, Tino Hausotte<sup>1</sup>*

<sup>1</sup> Institute of Manufacturing Metrology (FMT),

Friedrich-Alexander-University Erlangen-Nürnberg (FAU), Nögelsbachstraße 25, 91052 Erlangen  
florian.wohlgemuth@fmt.fau.de

## Summary:

The determination of measurement uncertainties in dimensional X-ray computed tomography measurement technology is a complex task for which many different influences have to be taken into account. This work examines the influence of the scan mode in combination with the number of projections and an eccentric clamping on the quality of the measurement. It shows that the workpiece positioning has a considerable influence on the result in the case of continuous scan mode. In addition, an application-dependent potential for reducing the lead times is described.

**Keywords:** X-ray computed tomography, measurement uncertainty, scan mode, workpiece positioning, dimensional metrology

## Background

Due to the many advantages such as non-destructive testing of internal geometries, X-ray computed tomography (CT) has become increasingly important in recent years [1]. The complex influences on the measurement result are not yet fully understood at this point and therefore require further investigation. While the influence of the focal spot size and detector unsharpness was evaluated in previous studies [2], the aim of this work is to investigate the effects of continuous scan mode on dimensional measurements. So far, the influence of object movements during a single exposure on the resulting deteriorated image quality has only been investigated in medical applications [3]. These investigations are also necessary to decide whether the influence of the continuous scan mode needs to be accounted for when attempting to numerically evaluate measurement uncertainties (compare to [4]).

## Theory

While a commonly used CT measurement mode works according to the start-stop principle, the measurement time can be reduced considerably by continuously rotating the turntable at a constant angular velocity. It can be assumed that a continuous movement only leads to a deterioration in the measurement if the movement of an individual projected object point during a single projection leads to an unsharpness that is in the order of magnitude of the detector unsharpness.

The following conservative estimate then applies to the minimum number of projections  $n_{min}$ :

$$n_{min} = \frac{2\pi \cdot R_{max} \cdot M}{\sigma_D} \quad (1)$$

$R_{max}$  is the maximum distance of an object point from the centre of rotation and  $M$  describes the magnification of the image on the detector.  $\sigma_D$  is the detector unsharpness (compare to [2]).

## Experimental Setup

To examine the influence of the measurement strategy, measurements with start-stop scan mode as well as continuous scan mode with centric and eccentric clamping (approximately 20 mm eccentricity) are carried out by using different numbers of projections. The CT system used is a Zeiss Metrotom 1500 (OS version 3.2.4.17214). The number of projections is significantly below the operating software-suggested value of 1400 and thus the CT system is operated outside of its specification. To enable a quantitative comparison, a calibrated test specimen made of aluminum is used (see Fig. 1).

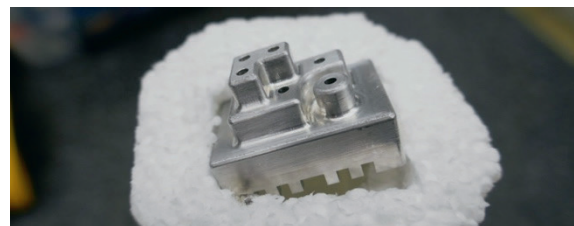


Fig. 1. Test specimen used

The tube was operated at 180 kV / 180  $\mu$ A and the detector at 1000 ms and 16x gain. 20 measurement repetitions are carried out for each configuration for sufficient statistics. To determine the measurement uncertainty, standard deviations and measurement deviations for 48 lengths, 29 radii and 29 roundnesses are evaluated using Volume Graphics VGStudio Max version 3.4 and MathWorks MATLAB 2018b.

## Results

Fig. 2 shows the systematic measurement error (bias) of the distance measurements, Fig. 3 the random measurement error (standard deviation). Both errors display similar behaviour; the random error is a factor of about three of the systematic error. Above 600 projections, continuous and start-stop mode are indistinguishable for centric clamping. Eccentric clamping leads to clearly higher random errors only for the continuous scan mode. The systematic measurement error also slightly increases for the start-stop mode in the case of eccentric clamping and low projection number – the effect for the continuous scan mode is however more pronounced.

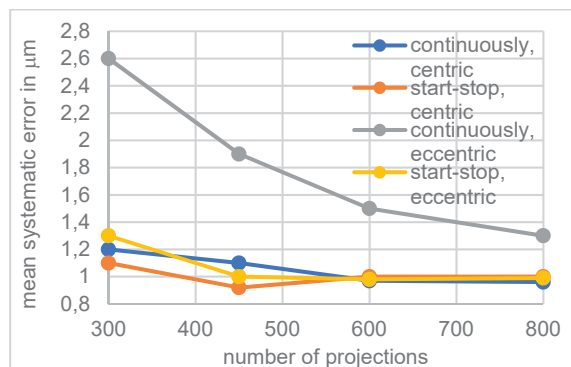


Fig. 2. Systematic error in distance measurements

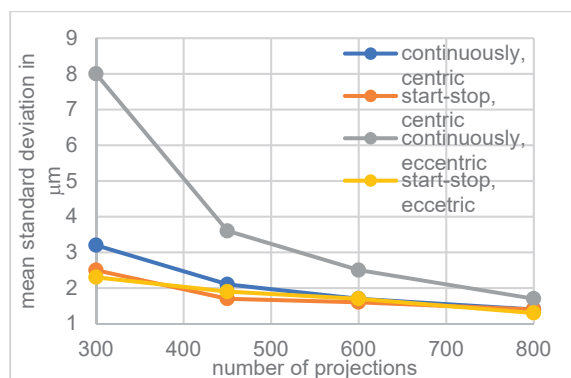


Fig. 3. Random measurement errors (standard deviation) in distance measurements

If the number of projections is very low, the measurement accuracy deteriorates due to the lack of data for the reconstruction. With projection numbers over 800, no additional improvement was achieved in further experiments. While the measurement in the start-stop mode is nearly

independent of the clamping position of the workpiece, this significantly influences the measurement values in the continuous mode. With more than 800 projections, the difference in the random error vanishes. This limit value can also be determined for an offset of 20 mm with eq. (1). The differences between the scan modes become significantly smaller with an increasing number of projections, especially for centric clamping. Radius and roundness measurements show a similar behaviour.

## Conclusions

Both the number of projections and the rotation axis distance have a decisive influence on the difference between start-stop and continuous scan mode. This is important because both the scan mode and the number of projections have a considerable influence on the measurement time and thus have potential to be optimized in industrial applications. For small and centrally clamped workpieces, for example, the throughput time could be significantly reduced without any major loss of information. In order to be able to estimate the potential, further measurements should be carried out with different offset configurations and suitable measurement objects. The data determined could then in turn be used to improve the simulation of measurement uncertainties. The results show that even outside of specification, the continuous scan mode of the Zeiss Metrotom 1500 can still perform as well as the discontinuous scan mode depending on measurement part, eccentricity and measurand.

## Acknowledgement

The authors would like to thank the German Research Foundation (DFG) for the financial support of the acquisition of the CT system Zeiss Metrotom 1500 through Grant No. 324672600.

## References

- [1] J. P. Kruth, M. Bartscher, S. Carmignato, R. Schmitt, L. De Chiffre, A. Weckenmann, Computed tomography for dimensional metrology, CIRP Annals - Manufacturing Technology 60, 821-842 (2011)
- [2] C. Orgeldinger, F. Wohlgemuth, A. M. Müller, T. Hausotte, Spot size and detector unsharpness determination for numerical measurement uncertainty determination, iCT 2019, Padova, Italy
- [3] W. Siman, S. C. Kappadath, Comparison of Step-and-Shoot and Continuous-Bed-Motion PET Modes of Acquisition for Limited-View Organ Scans, Journal of nuclear medicine technology 45(4), 290–296 (2017)
- [4] F. Wohlgemuth, A. M. Müller, T. Hausotte, Development of a virtual metrological CT for numerical measurement uncertainty determination using aRTist 2, Technisches Messen 85, 728-737 (2018)