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# Form measurements in an industrial CT scanner investigated using a polymer step gauge

A. Stolfi[1], J. Angel[2], L. De Chiffre[1]

[1]Department of Mechanical Engineering, Technical University of Denmark, Building 425, Produktionstorvet, DK-2800 Kgs. Lyngby, Denmark
[2]SONION A/S, Byleddet 12-14, DK-4000 Roskilde, Denmark

alesto@mek.dtu.dk

**Abstract**

Computed Tomography (CT) is a promising technology for both geometrical measurements and form measurements. However, a number of influence factors such as magnification, threshold determination strategies, and position of feature in the CT volume, have effect on the CT measurement performance. The present investigation concerns the measurement of flatness at different positions in the CT measurement volume using a milled miniature step gauge. The artifact is a 42 mm long step gauge with 11 grooves at 2 mm steps, made of polyphenylene sulphide PPS ($\rho$ = 1.650 g/cm$^3$), with limited form error and good surface finish. A total of 132 flatness measurements were performed on the left step gauge grooves. The linear distribution of the grooves pointed out a non-uniform CT performance over the step gauge length with max deviation up to 25 µm. However, an appropriate choice of parameters yielded a reduction of the max deviation along the step gauge length by approximately 13 µm.

Keywords: Form measurements, industrial CT scanner, step gauge

## 1. Introduction

The continuously shortening product life cycle demands a quicker response speed and a lower defect rate in industrial productions. Therefore, quality control is becoming one of the most demanding problems in modern manufacturing. In this context, Computed Tomography (CT) represents a new accepted inspection tool [1]. CT, compared to conventional tactile or optical measurements, establishes in the high density of information produced with a single scanning and possibility to measure inaccessible internal features the most important advantages [2]. On the other hand, the large number of influence factors, in some cases not yet quantifiable, undermines the potential industrial applications as tool for quality control. The work described here aims to highlight the non-uniform behaviour of a CT scanner when similar objects are positioned within of CT volume at the same time. Variables such as magnification and threshold determination strategies are taken into account. The quantification of non-uniformity was based on flatness measurement of a polyphenylene sulphide (PPS) step gauge [3]. The item, devised and manufactured, as well as calibrated, at DTU, allows simulating objects situated in the CT volume. Because of the milling process used, the step gauge presents limited form error (approximately 3 µm) and good surface quality (Ra = 0.82 µm).

## 2. Experimental investigations

The experiment was carried out using a GE Phoenix-xray Nanotom M at the Technical Research Institute of Sweden SP. The reconstruction was performed using software phoenix datos|x 3D provided by GE. For determination of the surface, inspection software VG Studio MAX 2.2 from Volume Graphics was used. The object was positioned at 45˚ in order to reduce the border noise [3] and it was not repositioned during runs of the experiment. The variables investigated were: three levels of magnification and the threshold determination strategies applied (ISO-50% and adaptive approach). Approximately 1000 points at 0.04 mm steps were fitted to define each geometrical primitive. An overview of the variables is shown in Table 1. Other scanning parameters were based on previous investigations on PPS step gauges [3]. The object was glued on a carbon tube and clamped in the chuck (see Fig. 1). The scale error correction was performed using a ball plate developed at DTU [4].

**Table 1** Parameters setup used.

| Parameter | Setup - 1 | Setup - 2 | Setup - 3 |
|---|---|---|---|
| Magnification | 1.8 | 2.2 | 2.5 |
| Voxel Size | 28 µm | 23 µm | 20 µm |
| Threshold strategies | ISO-50% | ISO-50% | ISO-50% |
| | Adaptive | Adaptive | Adaptive |

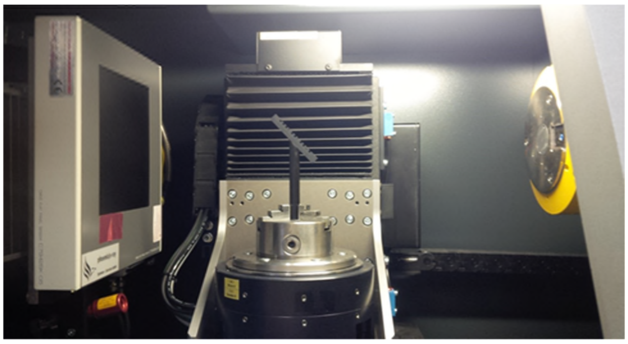


**Figure 1.** Orientation of the step gauge in the scanner cabinet. From left: X-ray detector, step gauge fixed in the rotary table and X-ray source.

## 3. Results and discussion

According to the calibration procedure [3], the first reference groove was identified as shown in Fig. 2. A total of 132 measurements were performed on the left flanks using one replication. Taking into account only the average value for each groove, the values are shown in Fig. 3. In order to makes easier the comparison among configurations, the overall average and the maximum deviation, averaged along the step gauge length, are selected and collected in Table 2.

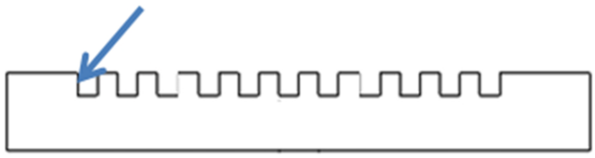
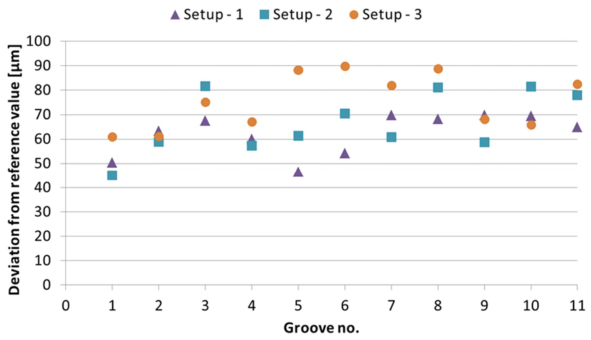
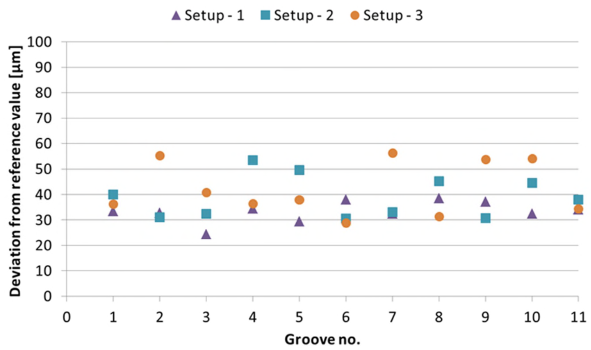


**Figure 2. Identification of the 1st groove (arrow).**




(a)




(b)

**Figure 3.** Flatness errors calculated as a difference between CT and reference measurements for each combination of magnification and threshold determination method: ISO-50% (a) and Adaptive (b).

**Table 2** Average and maximum deviation for each configuration (values in µm).

| Setup | ISO-50% | Adaptive | Max dev ISO-50% | Max dev Adaptive |
|---|---|---|---|---|
| 1 | 59 | 32 | 23 | 14 |
| 2 | 67 | 39 | 25 | 23 |
| 3 | 68 | 42 | 28 | 27 |

The linear distribution of the grooves makes it possible to reveal a non-uniform CT performance over the CT volume. Deviations up to 28 µm were observed over the step gauge length scanned under same conditions. Such occurrences can be due to Feldkamp effect and axis tilt that influence the sharpness of flanks and leading to mismeasurements [5].

Although the deviations are important, an improvement of CT performance in terms of maximum deviation was achieved by using Setup-1-Adaptive (see Fig. 4). In fact, the lowest magnification produced a reduction of blurring along the step gauge length and a smaller cone-beam angle with advantages in terms of maximum deviation along the object length (only 14 µm). Still, the data show a possible mathematical relation that links the accuracy of measurements and the magnification.

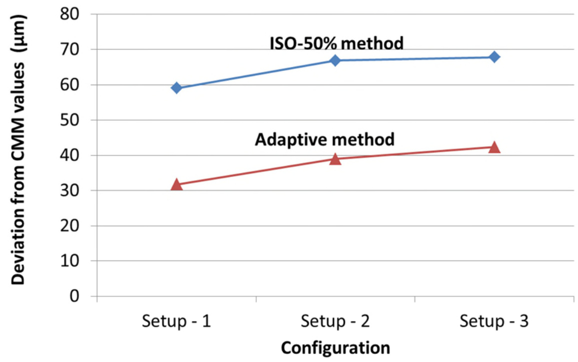



**Figure 4.** Comparison among average measurement results for each configuration. A possible trend can be identified.

## 5. Conclusions and outlook

Using a miniature PPS step gauge and its linear extension, a clear influence of the measurand position, within of CT volume, on the achievable CT performance was identified. In addition, a possible mathematical relation between accuracy of CT measurements and magnification levels was identified. A further investigation taking into account more levels of magnification will be designed.

## 6. Acknowledgements

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