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Geometrical metrology on silicone rubber by computed tomography

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Abstract

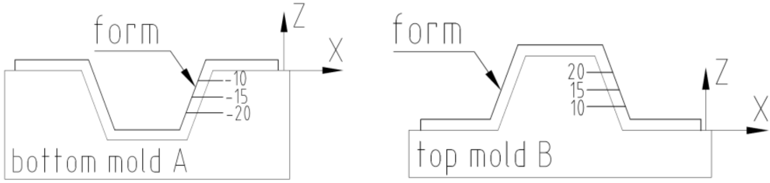
Computed tomography (CT) represents a suitable measuring technique for investigation of deformable materials, since no forces are developed on the part during scanning. As for any other measuring instruments, the traceability of the CT scanners needs to be assured. An investigation on geometrical measurements on silicone rubber using CT was carried out. Measurements performed on a CT scanner were compared to measurements on a coordinate measuring machine (CMM), being used as reference.

1 Introduction

When CT scanning has been first introduced, this technique was used for medical purposes. Since 1980's CT scanning has been integrated into industry and used for non destructive testing of materials. During the last few years CT scanning has been increasingly used for coordinate metrology. One of the main advantages of CT scanning is to measure objects without destroying them. Using CT scanning, nearly all materials can be scanned. The material used in the present work is silicone rubber (ESSIL 291). It is a silicone system with a 291 catalyst. The product under investigation is a cake form. Process chain for development of this product can be briefly described as follows: 1. development of a CAD model of the cake form, 2. manufacture of the top and bottom molds by milling, 3. preparation of the silicone rubber (mixing of the silicone rubber and the catalyst, de-gassing), 4. casting, 5. elimination of the air bubbles in the vacuum chamber, 6. solidification in the polymerization oven, 7. getting the silicone rubber cake form.

2 Setup

The silicone rubber cake form was measured using the polyamide mold as support. The mold is composed of a bottom (A) and a top (B), parts from which the form was obtained. The diameter on the cone was measured at three given heights (-10, -15 and -20mm for Form on A and 10, 15 and 20mm for Form on B, with respect to Z-axis of the coordinate system), see Figure 1.



a) Form on A. b) Form on B.

Figure 1: Measuring strategy.

A UPMC 850 CARAT CMM from Zeiss and a Metrotom 1500 cone beam CT scanner from Zeiss, kindly provided by Danish Technological Institute, were used for the investigation. Measurements performed on the CMM were considered to be reference measurements. This is due to the fact that measurements performed using contact technology generally speaking result in better precision, higher repeatability and ensures traceability of the measurement. Measurements performed on CMM were realized using a probe of 8mm diameter and a probing force of 0.2N. All the measurements performed on the CMM were reproduced three times. Measurement setup for CMM measurements is shown in Figure 2a. Both form and mold materials are suitable for measurements using CT. These materials are highly penetrable for X-rays to pass through and therefore allowing a reconstructed object in high contrast resolution. During acquisition, the test part was positioned on the rotary table of the CT scanner under the inclination of approximately 45° (see Figure 2b). This setup enables the best acquisition of the test part because the length that the X-rays travelling through the object is equally distributed along all angle positions. All the measurements performed on the CT scanner were reproduced three times. The geometrical magnification was 1.5x with voxel size of 267µm. Software for reconstruction of a 3D model was CALYPSO CT. After surface extraction, the model was saved in the STL format and software, GOM ATOS, was used to perform geometrical measurements.

a) CMM measuring setup. b) CT measuring setup.

Figure 2: Measurement setup for the form on B.

3 Experimental investigation

Due to the high elasticity of silicone rubber, investigation on deformation effect of the form was carried out on the CMM. This was used for compensation of diameter measurements. It was found that higher probing force results in smaller coefficient of variation and higher measuring reproducibility. Two measuring strategies on CMM were realized: single point probing (SPP) and probing in scanning mode (SMP). It was found that SMP results in smaller standard deviations but the difference was not significant and since SPP measuring strategy is generally used for measuring a big variety of parts, this latter was used for further comparisons between CMM and CT measurements. The uncertainty evaluation using GUM [1] was performed. Three factors contributing to the expanded measurement uncertainty U (see Equation 1) were considered. These factors are the measuring instrument (u_{ins}), the measurement process (u_p) and the temperature effect (u_{temp}). Expanded measuring uncertainty is calculated at 95% confidence interval (k=2).

$$U = k \cdot \sqrt{u_{ins}^2 + u_p^2 + u_{temp}^2} \qquad \text{Equation 1}$$

The measuring instrument considers its MPE value (MPE_{CMM}=0.4+L/900, MPE_{CT}=9+L/50), measurement process is connected to the measurement reproducibility including three measurements and the temperature effect represents the environment changes during measurements.

4 Results

The uncertainties for measurements on the CMM were for both cases, including measurements of the form on the supported top and bottom molds, calculated

U(k=2)=0.016mm. Uncertainty of measurements on the CT scanner was calculated U(k=2)=0.058mm when the form was measured on the supported top mold and U(k=2)=0.183mm when the form was measured on the supported bottom mold. It was experienced that the diameter of the cone measured at different height levels by CT scanner was smaller by 0.197mm compared to measurements performed on the CMM when the form was measured on the supported top mold and the diameter of the cone was bigger by 0.267mm in the case the form was measured on the supported bottom mold (see Figure 3). This behaviour was probably caused due to high transparency to X-rays of the form material. Another reason for diameter differences could be due to the determination of the threshold value. As it was shown for example in [2], threshold value changes in the opposite way for measurements of external and internal features.

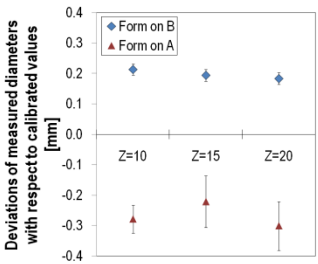


Figure 3: Deviations of measured diameters with respect to calibrated values, measured at three defined height levels according to measuring strategy explained in Figure 1.

5 Conclusion

A procedure for measurement of highly deformable part, such as silicone rubber form, was developed. Measuring uncertainties for CT measurements were calculated in a range which is reasonable when considering such deformable sample, such as silicone rubber. Therefore, CT scanning is highly recommended measuring technique, resulting in short measuring times and measuring of complicated features.

References:

[1] ISO/IEC Guide 98-3:2008 - Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement (GUM:1995).

[2] Carmignato S. (2007). Traceability of dimensional measurements in computed tomography. In: Proceedings of 8th A.I.Te.M. Conference; 2007, ISBN/ISSN: 88-7957-264-4.