INFLUENCE OF SURFACE DETERMINATION ON CT MEASUREMENT RESULTS

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Sažetak

Računalna tomografija relativno je nova metoda u području dimenzionalnog mjeriteljstva. Metoda omogućava provedbu nerazornih mjerenja i analiza unutarnje i vanjske geometrije predmeta mjerenja. Računalnom tomografijom omogućena je provedba većeg broja različitih analiza na istom modelu dobivenom skeniranjem rendgenskim zrakama, što metodu čini interesantnom u širem području primjene. Međutim, mjeriteljska sljedivost i mjerna nesigurnost rezultata mjerenja još uvijek nisu osigurane i uspostavljene. S obzirom na to da je procjena mjerne nesigurnosti rezultata mjerenja jedan od preduvjeta šire implementacije metode u području dimenzionalnih mjerenja, velik broj istraživanja usmjeren je prema rješavanju tog pitanja. U cilju osiguravanja mjeriteljske sljedivosti potrebno je identificirati parametre prisutne u procesu mjerenja te odrediti njihov utjecaj na rezultate mjerenja. Jedan od značajnijih parametara jest odabir granične vrijednosti sive skale. U ovom radu razmatran je i istražen utjecaj odabira granične vrijednosti sive skale na rezultate mjerenja aluminijskih cilindara različitih površinskih hrapavosti dobivenih računalnom tomografijom.

Ključne riječi: *računalna tomografija, granična vrijednost sive skale, dimenzionalna mjerenja*

Abstract

Computed tomography is a relatively new method in a field of dimensional measurement. The method allows non-destructive measurements and inspections of both inner and outer objects geometries. Also, the method allows conduction of different analysis on the same model obtained by one CT scanning which makes it very desirable in wide range of use. However, metrological traceability and measurement uncertainty are still not assessed and achieved. Since the prerequisite for wider implementation and use of the method for purposes of dimensional measurement is assessment of measurement uncertainty, many researches are focused to address this matter. In order to achieve metrological traceability, influence parameters as well as their impact on measurement results need to be defined. One of the main parameter is threshold determination. This paper deals with influence of threshold determination on CT measurement results of aluminium cylinders with different surface roughness.

Keywords*: computed tomography, threshold determination, dimensional measurements*

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1. INTRODUCTION

Requirements in production nowadays include production of more complex inner and outer object geometries. Problem which arises is how to non-destructively inspect and measure inner geometry accurately [1]. Since additive technologies are increasingly used in production, this also requires a suitable measurement method. One of the promising solutions is measuring with computed tomography. The method enables inspection of both inner and outer geometry on the same model, as well as, conduction of many different analyses such as pore/inclusion inspection, wall thickness analysis, comparison with CAD model etc [2,3]. Use of computed tomography for purposes of dimensional measurement started in beginning of 2000 when first industrial CT scanner was presented at Control fair in Germany [3]. Since then, applications of the method in industrial field significantly rose. The method is an answer to new production technologies and approaches, such as rapid prototyping and reverse engineering. It is a method that allows non-destructive 3D measurements either by nominal/actual comparison or by fitting objects of simple geometry [4]. Dimensional measurement with computed tomography can be divided in three separate sub processes; CT scanning, model reconstruction and dimensional measurement. Each sub process is defined by many factors that influence measurement process and measurement results [5]. Since the exact influence of factors on measurement results is not known, metrological traceability is still not achieved [6-8]. One of the biggest problems is how to accurately define the border between material and background, when measuring mono-material objects, and how to define borders between different materials and background when measuring multi-material objects. In ideal case, when measuring mono-material objects, there will be two different gray values, one representing background and one representing material. However, due to different influence parameters either in scanning or reconstruction process, different phenomena appears at the voxel model that complicate surface determination process. These phenomena are systematic errors named CT artifacts. According to ISO 15708-1 CT artifacts are described as discrepancies between the actual value of some physical property of an object and the map of that property generated by a CT imaging process [9]. Artifacts cause different gray values along objects' edges which can lead to incorrect edge determination and later incorrect measurement results. Defining a correct and accurate threshold value is one of important steps in metrological traceability achievement. At the moment there are a few approaches in surface determination process. This article analyses and compares results obtained by measuring aluminium cylinder using different surface determination approaches using VG Studio MAX software.

2. MATERIALS AND METHODS

2.1. Aluminium cylinders

Influence of different methods used to define threshold value of 3D voxel models, obtained by computed tomography, was evaluated on six aluminium cylinders with different surface roughness. All cylinders were made from the same material, aluminium, at the same CNC turning machine by the same operator. Cylinders are given in Figure 1.

Fig. 1: Aluminium cylinders

Surface roughness was measured using Taylor Hobson Surtronic25 roughness tester according to ISO 4288:1966 and ISO 4287:1997. Surface roughness was observed by measuring two amplitude parameters *Ra* (arithmetic mean deviation of the assessed profile) and *Rz* (maximum height of the profile), and one spatial parameter *RSm* (mean spacing of profile elements). Results are given in Table 1.

Tab 1: Measured surface roughness parameters of aluminium cylinders

	1	**2**	**3**	**4**	**5**	**6**
***Ra*, µm**	1,45	2,05	3,77	5,57	6,98	10,2
***Rz*, µm**	6,8	10,3	16,9	21,3	27,8	41,0
***RSm*, µm**	112	168	214	320	350	469

2.2. Reference measurements

Reference measurements of outer diameters were conducted in repeatability conditions using TESA Micro Hite 3D CMM. Each cylinder was measured five times with reference method. Results of reference measurements are given in Table 2.

Tab 2: Reference measurements obtained by CMM

Cylinder	**Outer diameter, mm**
1	11,958
2	11,966
3	11,995
4	11,955
5	11,964
6	12,024

2.3. CT measurements

CT measurements were conducted using industrial CT scanner. All samples were scanned using the same X-ray source setups. Objects were placed at the polystyrene basis in a slightly tilted orientation. All cylinders were scanned at the same geometrical magnification together with calibration rod, which was later used for voxel size correction.

After reconstruction process was done, all cylinders were analyzed using VG Studio MAX 3.0 software. Before making measurements or performing any analysis of a model, the border between object and background has to be determined. Since in observed case only mono-material objects were inspected, two gray values need to be defined, one for material (aluminium), and one for background. Software which was applied for conduction of measurements offers several approaches for surface determination. Here, three approaches were used and analyzed in case when measuring objects with significantly different surface roughness. Firstly, global threshold method was used. The method is suitable in cases when scanning homogenous materials such as aluminium where, under ideal conditions, it would be possible to define the component surface simply by determining the grey value threshold [10]. Threshold could be calculated as the mean value from the material grey value and the image background grey value [10]. The result of global threshold method is a material boundary defined alongside whole object by one gray value, so called threshold value.

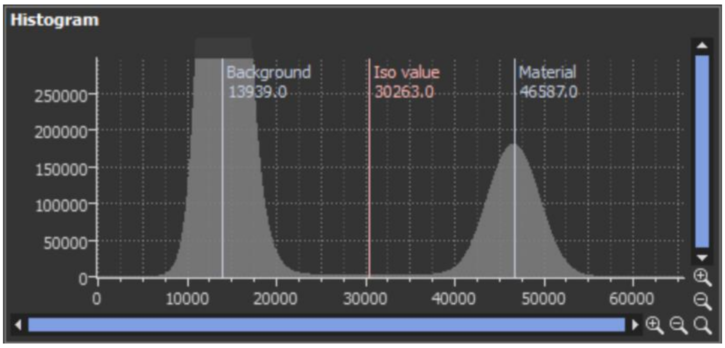

Fig. 2: Histogram: global threshold surface determination method applied on cylinder 1

Second approach was the local adaptive approach, which defines locally adapted gray values. This approach is well suited and used in cases with big variations in gray level due to presence of image artifacts. The same grey value, which can be determined by using global threshold method, will be interpreted differently depending on the surrounding voxels [11].

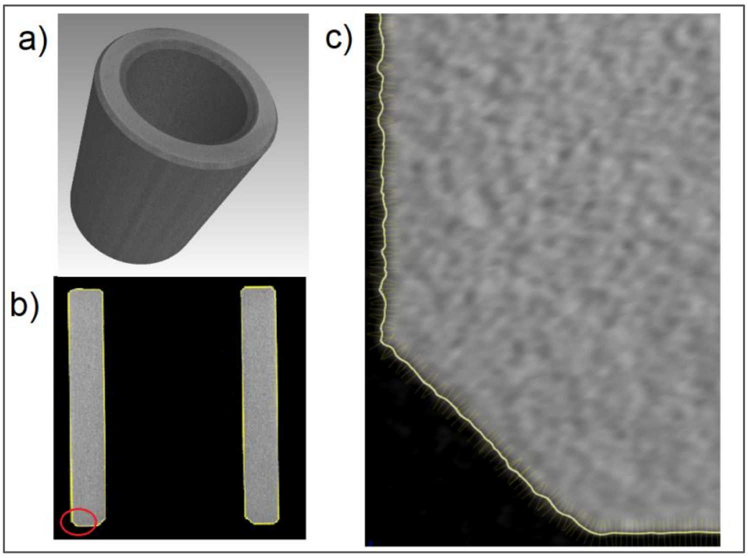

Fig. 3: Local adaptive surface determination method: a) CT model of cylinder 1, b) 2D slice image, c) magnified border on 2D slice image

Third applied and analyzed approach was manual surface determination conducted by using sample area on CT data scans. The procedure implies determination of grey values by selecting sample area that belongs to material, respectively to background.
After the surface was determined, measurement of outer diameters was carried out. Used measuring approach considered fitting simple geometry objects, in observed case fitted were cylinders. In total 1000 points was used to describe simple geometry, using Gaussian method.

3. RESULTS AND DISCUSSION

Measurement results of six aluminium cylinders were analyzed in dependence of applied surface determination method and object surface roughness. All results were compared to reference values obtained by using CMM method. The results are given graphically as deviations from reference values. Outer diameters were observed.

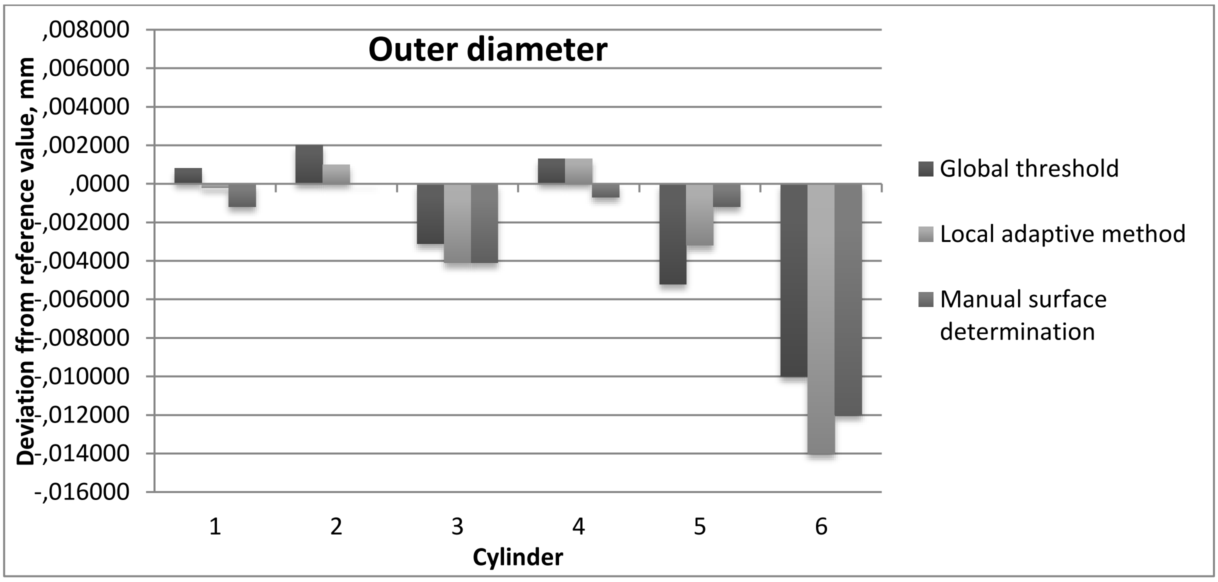

Fig. 4: Measurement results for surface determination approaches on aluminium cylinders

By comparing deviations from reference values both depending on surface roughness and applied surface determination method in cases with lower surface roughness the best results were obtained when using local adaptive surface determination method. Contrary to that, when measuring diameter on cylinder with the highest observed surface roughness, cylinder number 6, the lowest deviation is obtained when using global threshold method. In the case of measuring outer diameters of cylinders 1, 2, 3 and 4, analysis of variance was performed. Obtained *p*-value was larger than alpha risk, which means that there is no significant difference between results. Deviation in results which are still present cannot be attributed to the choice of surface determination method. When measuring objects with higher surface roughness, here cylinders 5 and 6, more significant differences in measurement results with regard to the chosen method were observed.

4. CONCLUSION

In this research influence of surface determination on CT measurement results was observed. Six aluminium cylinders with significantly different surface roughness were measured using computed tomography method where three different approaches in surface determination were used. Measured were outer diameters and results were compared to reference values measured by coordinate measuring machine. Obtained results indicates that there is no significant difference between results obtained by using different surface determination approaches on observed cylinders with lower surface roughness. Deviation in results which are still present cannot be attributed to the choice of surface determination method. Opposite to that, when measuring objects with higher surface roughness, lower deviations can be observed when applying local adaptive method.

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