

Comparison of the Cylindricity Deviation Using Different Evaluation Methods

Miroslav Dovica*, Alexander Vég

Technical University, Mechanical Engineering Faculty, Department of Biomedical Engineering and Measurement, Košice, Slovakia
*Corresponding author: miroslav.dovica@tuke.sk

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Abstract This paper deals with the measurement and the evaluation of cylindricity deviation of the rotational symmetrical workpiece. Coordinate Measuring Machine (CMM) with X-Ray tomography was used for the measurement. For the evaluation of the cylindricity deviation, we applied standard Gaussian cylinder. Data obtained by the measurement is compared using the VG Studio and Calypso software. At the end of this paper, the experimental data is presented.

Keywords: cylindricity deviation measurement, coordinate measurement machine, X-ray

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1. Introduction

The goal of the form measurement is to control if the tolerances and specifications defined by the designer are met. In the mechanical engineering, about 85 % of measurement tasks are dedicated to the measurement of contoured surface. The measurement of cylindricity and the evaluation procedures performed according to ISO standards are the important inspection tasks.

The real workpieces manufactured with the advanced production technologies have a large number of tolerances that must be measured. A primary concern is to determine how broad the tolerance may be without affecting other factors or outcomes of the process. Coordinate metrology has become essential for industrial dimensional metrology. CMMs are can measure a wide range of geometrical parameters. Optical non-contact inspection techniques have revolutionised inspection applications in the last decade. In this paper, the X-ray computed tomography (CT) has been used for the measurement of cylindricity deviation.

2. Terms and Definitions

Our approach is to measure and analyse the cylindricity in order to understand the concept of tolerance, deviation and measurement result, including the measurement uncertainty. In drawing documentation, the term tolerance is used for modelling the accuracy of particular features. The cylindricity tolerance controls the entire surface of a cylinder. [1] According to ISO 1101, the cylindricity deviation is a sum of maximum radial distances of the workpiece surface from the reference cylinder on both its sides, i.e. the range of local deviations of the workpiece surface from the reference cylinder. The reference

cylinder should be consistent with the material minimum requirement.

2.1. Geometrical Features

From the terminology point of view, every level of the workpiece development, from the drawing to its production and quality control, should be clearly defined. According by ISO 14660-1, the levels of the workpiece development are shown in Figure 1 and defined as follows:

- nominal integral/derived feature,
- real GPS feature,
- extracted integral/derived feature,
- associated integral/derived feature.

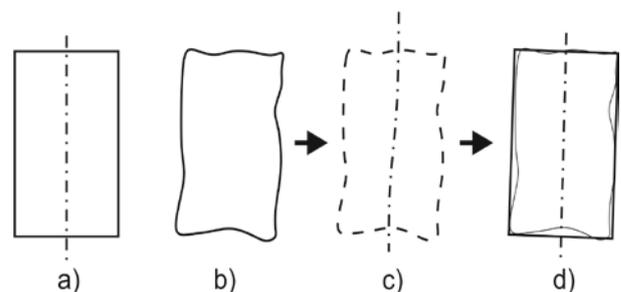


Figure 1. Development of the workpiece

In the measurement analysis (Figure 1c) d)), the extracted features are used. These features are obtained from the finite points of the measurement of a real workpiece. Minimum number of points is given by the definition of features. [2,11]

2.2. Concept of the Cylindricity Tolerance

Cylindricity tolerance belongs to the group of form characteristics. Standard ISO 1101 recognises six different types of form tolerances as shown in the Figure 2. [3]

Type of tolerance	Geometric characteristics	Symbol
Form	Straightness	
Form	Planarity (flatness)	
Form	Circularity	
Form	Cylindricity	
Profile	Profile of a line	
Profile	Profile of a surface	

Figure 2. Types of form tolerances

By the definition of cylindricity, the minimum zone requirement defines such arrangement of two coaxial cylinders that the radial distance between them is minimised. Tolerance zone is defined by two coaxial cylinders. In order to inspect the form deviation, the entire surface of the real cylinder must not exceed minimum distance of two coaxial cylinders regardless the dimension of the cylinder Figure 3.

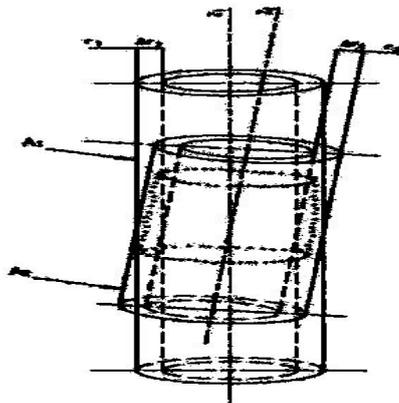


Figure 3. Concentric cylinders (ISO 1101) [4]

2.3. Methods of the Evaluation of Cylindricity Deviation

Design form of the tolerated geometrical features is defined by features of geometrical ideal form of cylinders. For the cylindricity deviations, it is important to note that the default evaluation must be performed by the minimum zone method as defined in the standards (ISO 1101) Figure 4, i.e. MZCY - minimum zone (feature) cylinder (ISO 1101), MICY - maximum inscribed (reference feature) cylinder, MCCY - minimum circumscribed (reference feature) cylinder, LSCY - least-squares (reference feature) cylinder

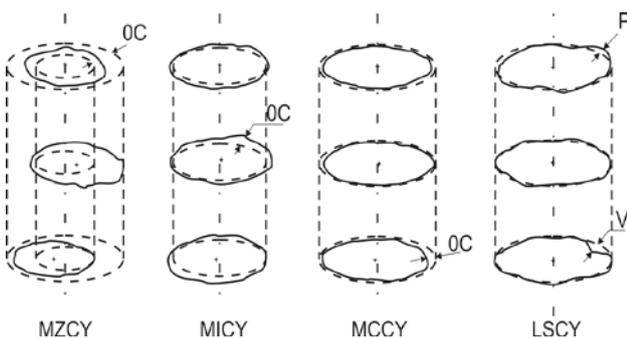


Figure 4. Methods of cylindricity evaluation

3. Experiment

A 3DCT system as shown in Figure 5 consists of:

- an X-ray source,
- a rotary table,
- an X-ray sensitive detector.

During a full discrete turn of the specimen, penetration im-ages which contain the spatial X-ray attenuation are recorded.

Using these images it is possible to reconstruct the fully inner and outer structure of the specimen. The reconstruction method used within this work is a Filtered Back-projection.

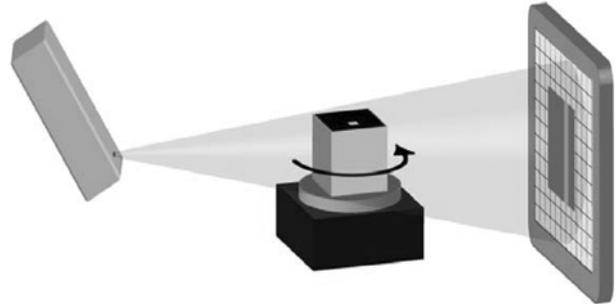


Figure 5. Principle of cone beam CT system [12]

The measurement has been performed by CMM Metrotom 1500 made by ZEISS Figure 6 with following metrological parameters:

- maximum permissible error for length measurement with Metrotom 1500 is $MPEE = (9 + L/50) \mu m$
- cylindrical measuring volume has the size of (300xΦ350) mm and flat detector panel is with the resolution of (1024x1024) pixels
- power of X-ray tube can be adjusted up to 225W (225 kV and 1 mA)
- performance value depends on the size and the material density of measured workpiece. [5]

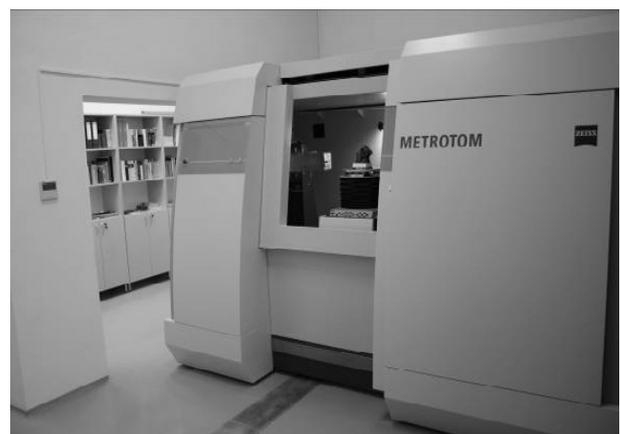


Figure 6. Coordinate measuring machine

The industrial CT scanning machine, such as the Zeiss Metrotom, a tube generates X-rays that penetrate into the workpiece while it rotates on a mat. An X-ray detector on the other side of the workpiece absorbs and interprets the X-rays. The results obtained by the measurement depend on the combination of the size of the workpiece and its material density. [6] For the evaluation of cylindricity deviations, we used VG Studio and Calypso software.

Initial conditions of the setting and evaluation of the grey value stayed the same. Grey value threshold is a segmentation technique that is commonly used when reconstructing the tomography machine. The threshold is defined as a portion of the maximum grey value from the interval between 0 and 1.[7] In case of VG Studio software, ISO Surface = 30399 was converted to threshold of 0,464. In case of Calypso software, threshold was 0,464. In order to visualise the scanned object, Calypso software uses parameter of triangles. The number of triangles is usually given by the dataset. [7,8] In our experiment, the number of triangles is 2 000 000.

Figure 7 shows the SolidWorks 3D model workpiece in four representations.



Figure 7. 3D CAD model of workpiece

Figure 8 shows the drawing of workpiece with nominal dimensions.

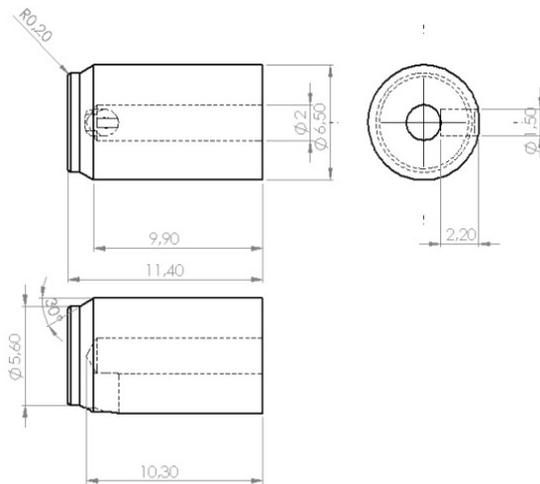


Figure 8. 2D CAD model of workpiece

To evaluate the measured data, we used the LSCY method. Figure 4 The data was processed in VG Studio and Calypso software. The diameter of the workpiece is $D = 6,5mm$ and the scanning time is $t = 2600sec$.

In VG Studio software, the point cloud parameter is used only for volume visualisation.. The number of points depends on the size of the workpiece.

Protocol Calypso and VG Studio protocol Figure 9 shows the measured cylindricity deviation- $\Delta_1 = 0,0129mm$ resp. $\Delta_2 = 0,013mm$ and nominal cylindricity tolerance $T = 0,02mm$.

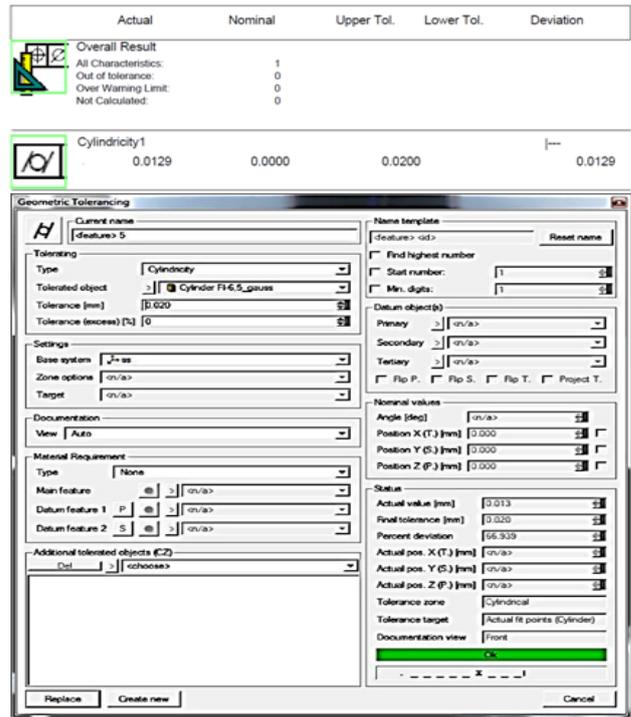


Figure 9. Protocol Calypso and VG Studio

In Calypso software, there are two methods for the evaluation of cylindricity deviation, i.e. method of roundness profile and method of generatrix lines Figure 10.

Calypso protocol presents the values of cylindricity deviation Figure 10. The roundness profile method obtains deviation cylindricity of $\Delta_3 = 0,013mm$ and nominal cylindricity tolerance of $T = 0,02mm$. The generatrix lines method obtains the cylindricity deviation of $\Delta_4 = 0,012mm$ and nominal cylindricity tolerance of $T = 0,02mm$.

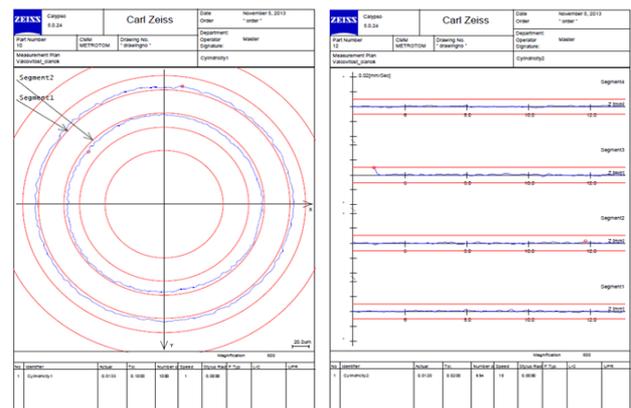


Figure 10. Calypso graphical protocol of cylindricity deviation

4. Conclusion

We used different measurement and evaluation methods in order to compare the cylindricity deviation. The rotation symmetric workpiece was measured using contactless method by CMM Metrotom 1500 and we used the point cloud parameter for the evaluation. The differences in cylindricity deviations obtained by VG Studio and Calypso were caused by mathematical models which were used by the evaluation procedures. According

to our experiment, we obtain the minimal cylindricity deviation when the method of generatrix lines in Calypso software is applied. If we assumed the use of one measurement machine (CMM Metrotom) and the same measurement conditions, the cylindricity deviation might be used for the software comparison.

Acknowledgement

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