PRACTICAL APPLICATION OF THE BIRD-CAGE STRATEGY IN MEASUREMENTS OF OUT-OF-CYLINDRICITY

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Abstract − Standards concerning Geometrical Product Specifications recommend a „bird-cage" strategy of cylindricity measurements as a strategy that provides the most reliable results. The paper presents concept of adjustment of a typical radial instrument to cylindricity measurements with use of the "bird-cage" strategy and results of an experimental verification of the developed concept.

Keywords: measurement, cylindricity, bird-cage strategy

1. INTRODUCTION

Parameters and recommendations relating to cylindricity measurements are described in the standard ISO 12180 [1]. This standard is a link of the chain of GPS standards (where GPS stands for *Geometrical Product Specification*). According to standard ISO/DIS 12180-1, an entire cylindricity deviation can be regarded as a superposition of three types of deviations: a straightness deviation of the cylinder axis, a form deviation in the longitudinal section of the cylinder, and a form deviation in the cross-section of the cylinder.

Figure 1 presents examples of cylindrical surfaces with one predominating deviation:

− a straightness deviation of the cylinder axis (also called a mean line deviation) − this type of deviation occurs when the axis of nominally cylindrical element is actually a 2D or 3D curve,

− a form deviation in the longitudinal section (also called a relative diameter change) − this type of deviation occurs when the diameter of the cylindrical element is different in different cross-sections,

− a form deviation in the cross-section (in fact, it is a roundness deviation) − this type of deviation occurs if there are irregularities of form in individual cross-sections of the workpiece; this deviation may be shifted in a subsequent cross-section linearly, angularly or according to a more complex dependence.
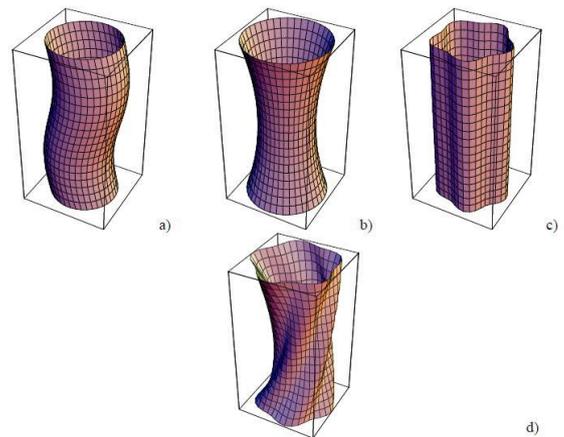

Fig. 1. Measuring strategies recommended by ISO 12180-1 [1]: a) the strategy for measurement of roundness profiles, b) the strategy for measurement of generatrix lines, c) the "bird-cage" strategy, d) the points strategy

Because the entire deviation of an cylindrical element is the superposition of components, there is a large number of parameters used for its description. ISO/DIS 12180 describes the following cylindricity parameters:

a) cylindricity deviation defined in relation to the so-called local cylindricity deviation (a local cylindricity deviation is the distance between the investigated point lying on the cylindrical surface and one on the surface of the associated cylinder). ISO/DIS 12180-1 defines an associated cylinder as:

− outer, or inner, or mean minimum-zone associated cylinder (MZCY),

− least-squares associated cylinder (LSCY),

− minimum circumscribed associated cylinder (MCCY) and

− maximum inscribed associated cylinder (MICY).

b) conicity and the conicity angle of the cylinder,

c) difference in the radii − this parameter is the difference between the maximum and the minimum radius of the circle associated with the cross-section of the cylinder according to the least squares formula,

d) straightness deviation of the generatrix,

e) straightness deviation of the extracted mean line.

Roundness deviations in selected cross-sections of a cylinder are related to roundness profiles and therefore are

described with the use of ISO 12181. Straightness deviations of local generatrix profiles and straightness deviations of the mean lines are related to straightness profiles and therefore are described with the aid of ISO 12780.

In order to obtain reliable results of cylindricity, it is necessary to apply a suitable measuring strategy [2-4]. The strategy should enable appropriate representation of the analysed surface, and appropriate density of measuring points. An important criterion for selecting a measuring strategy is the assumed predominant harmonic component of roundness and straightness profiles. In practice, it is hardly possible to measure a workpiece surface using the theoretical minimum number of points defined in ISO 12180-2. This standard describes other measuring strategies as well. The strategies provide specific information on a workpiece, yet their application is limited, as they do not make it possible to evaluate the entire cylindrical surface. ISO 12180-2 describes four limited measuring strategies: the strategy for measurement of roundness profiles, the strategy for measurement of generatrix lines, the "bird-cage" strategy (which is a combination of measurement of roundness profiles and generatrix lines), and the point strategy. These measuring strategies are shown in Fig. 2.
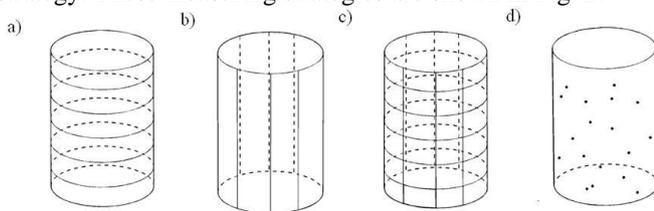

Fig. 2. Measuring strategies recommended by ISO 12180-1 [1]: a) the strategy for measurement of roundness profiles, b) the strategy for measurement of generatrix lines, c) the "bird-cage" strategy, d) the points strategy

The cross-sections and the longitudinal sections strategies are available in most modern radial instruments for measurements of form deviations. Accordingly, the points strategy is successfully applied to measurements of form deviations by coordinate measuring machines. However, the "bird-cage" strategy, which is recommended by the standard ISO 12180 as the strategy that gives most reliable results has not been so far used in measurements of cylindricity deviations.

There are two main reasons of this fact: The first one is that the measurement by the –bird-cage" method is much more laborious and time-consuming than other strategies described in the standard ISO-12180. The second reason is the fact that this strategy has not been sufficiently described mathematically so far. Therefore, it was necessary to develop methodology and procedures allowing for measurement of cylindricity deviation by the "bird-cage" strategy.

2. MEASURING EQUIPMENT

Solution of the problem of cylindricity measurements with the use of the bird-cage strategy required designing a special-purpose measuring system and equipping the software with procedures allowing calculation of reference features and cylindricity parameters. Efforts aiming at solving above mentioned problems were undertaken in the framework of the research project sponsored by KBN, no. 4

T07D 021 27, entitled " Evaluation of cylindricity profiles of machine elements by the combined method of roundness and straightness measurements – theoretical and experimental fundamentals". A theoretical analysis of the problem covered: superimposition of profiles in cross- and longitudinal sections, filtering the cylindricity profile after superimposition, calculation of parameters of reference cylinder and cylindricity parameters.

In order to carry out experiments, it was necessary to develop an unit for precise measurement of the angle of rotation of the measured element [4]. The unit shown in Fig. 3 consists of following components: an incremental encoder *MHK40-8-2000-5-B2-N*, a double linear receiver *uA9637*, a quadrant counter *LS7166*, a mictrocontroller *ATmega8515*, an interface USB/UART typu *FT232B* and a PC.
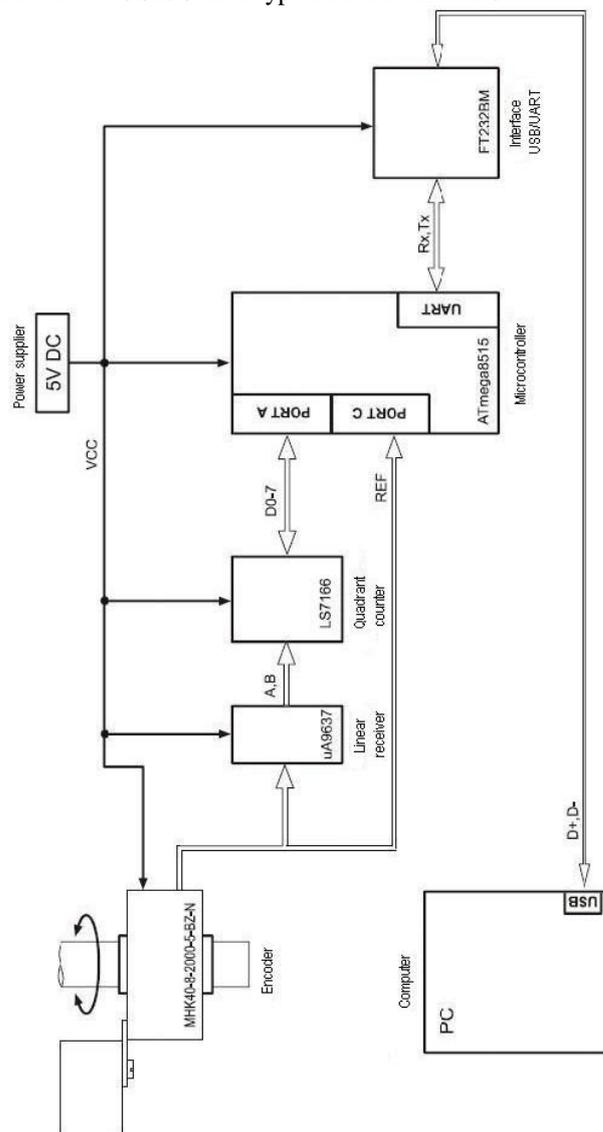

Fig. 3. Block scheme of the unit for precise measurement of the rotation angle

The unit shown in Fig. 3 was used to adjust the computer-aided instrument Talycenta by Taylor Hobson to measurements of cylindricity profiles by the „bird-cage" strategy. Talycenta is the device, which operation is based on the concept of radius change measurement. It is the device equipped with a rotary table [5-7]. The instrument is shown in Fig. 4.

Fig. 4. Computer-aided instrument for cylindricity measurements - Talycenta

3. EXPERIMENT

In the first stage of the experiment the set of four cylinders was measured with the use of the bird-cage strategy to check if procedures allowing profiles matching and filtering are correct. The results of measurements are given in Table 1.

Table 1. Measurement results of cylindrical workpieces with the use of Talycenta

Cylinder no.	Cylindricity deviation CYLt [µm]			
	Associated feature			
	LS		MZ	
	UPR range			
	15	50	15	50
1	2,33	2,67	2,34	2,56
2	2,81	3,03	2,71	2,96
3	2,65	2,77	2,45	2,68
4	2,13	2,61	2,04	2,30

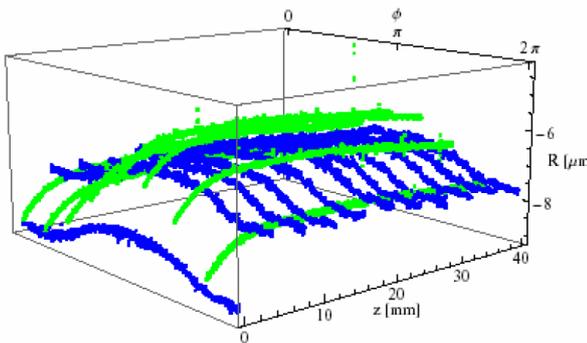An example of one of measured profile is shown in Fig. 5.

Fig. 5. Values of one of the measured profiles in cylindrical coordinates

The same profile after an application of filtering and matching procedures is shown in Fig. 6.
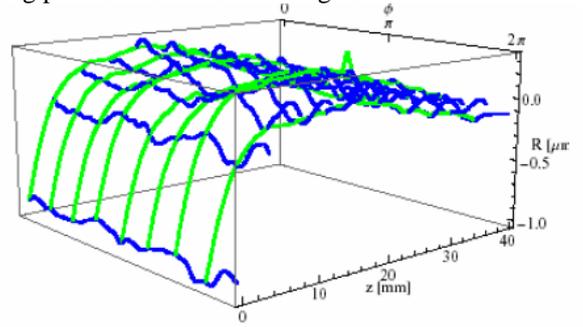

Fig. 6. Values of the profile shown in Fig. 3 after the procedure of filtering and matching

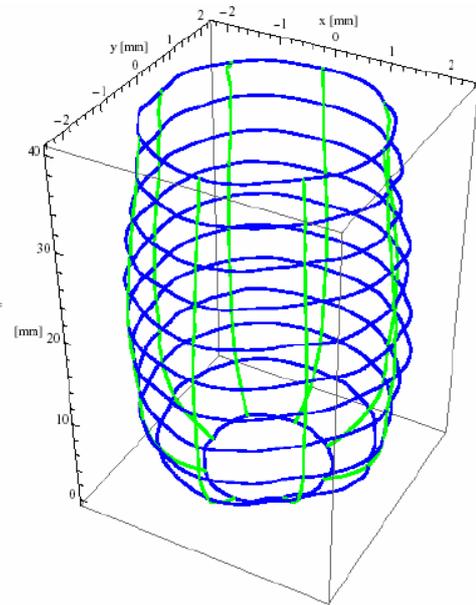The profile can be also represented in Cartesian coordinates, which is shown in Fig. 7.

Fig. 7. The profile after the procedure of filtering and matching in Cartesian coordinates

The cylindricity deviations of the elements were also measured with the use of highly accurate coordinate measuring machine PMM 654 by Leitz. In order to analyze differences between the results obtained by Talycenta and PMM 654 absolute and relative errors were calculated from following equations:

$$E_a = D_{TAL} - D_{CMM} \qquad (1)$$

$$E_r = \frac{D_{TAL} - D_{CMM}}{D_{CMM}} \cdot 100\% \qquad (2)$$

where:

E_a – absolute error,

E_r – relative error,

D_{TAL} – cylindricity deviation measured with the use of Talycenta (new method applying developed measurement units and procedures)

D_{CMM} – cylindricity deviation measured with the use of coordinate measuring machine.

The calculations were conducted for two ranges of harmonic components: 2-15 UPR and 2-50 UPR and for two types of

reference circles: the least squares circle and minimum zone circles.

Tables 2 and 3 show comparison of measurement results for the least squares circle. The tables provide also values of absolute and relative errors calculated according to equations (1) and (2). The results given in Table 2 were obtained for harmonic components range 2-15 UPR

Table 2. Comparison of measurement results (reference circle: LS , harmonic components range: 2-15 UPR)

Cylinder no.	PMM 654	Talycenta	Absolute error E_a	Relative error E_r
1	2,0	2,33	0,33	16,5
2	3,1	2,81	-0,29	9,35
3	2,5	2,65	0,15	6
4	2,4	2,13	-0,27	11,25

Respective results for the least square circle and for harmonic components range: 2-50 UPR are given in Table 3.

Table 3. Comparison of measurement results (reference circle: LS , harmonic components range: 2-50 UPR)

Cylinder no.	PMM 654	Talycenta	Absolute error E_a	Relative error E_r
1	2,0	2,67	0,67	33,5
2	3,1	3,03	-0,07	2,26
3	2,5	2,77	0,27	10,8
4	2,4	2,61	0,21	8,75

Tables 4 and 5 show comparison of measurement results for minimum zone circles. The tables provide also values of absolute and relative errors calculated according to equations (1) and (2). The results given in Table 4 were obtained for harmonic components range 2-15 UPR

Table 4. Comparison of measurement results (reference circles: MZ, harmonic components range: 2-15 UPR)

Cylinder no.	PMM 654	Talycenta	Absolute error E_a	Relative error E_r
1	2,0	2,34	0,34	17
2	3,1	2,71	-0,39	12,58
3	2,5	2,45	-0,05	2
4	2,4	2,04	-0,36	15

Respective results for the least square circle and for harmonic components range: 2-50 UPR are given in Table 5.

Table 5. Comparison of measurement results (reference circles: MZ, harmonic components range: 2-50 UPR)

Cylinder no.	PMM 654	Talycenta	Absolute error E_a	Relative error E_r
1	2,0	2,56	0,56	28
2	3,1	2,96	-0,14	4,52
3	2,5	2,68	0,18	7,2
4	2,4	2,30	-0,1	4,17

4. CONCLUSIONS

The "bird-cage" strategy has not been applied to measurements of cylindricity deviations so far, despite the fact that it provides most reliable results. There are two main reasons of this fact: The first one is that the measurement by the –bird-cage" method is much more laborious and time-consuming than other strategies described in the standard ISO-12180. The second reason is the fact that this strategy has not been sufficiently described mathematically so far. Therefore, it was necessary to develop methodology and procedures allowing for measurement of cylindricity deviation by the "bird-cage" strategy. It involved to design special-purpose measuring system and equipping the software with units allowing for calculation of reference features and cylindricity parameters for this strategy. The measuring system consisted of Talycenta instrument equipped with a special-purpose unit for precise measurement of a rotation angle of a specimen.

The results given in Tables 2-5 show that for the range 2-15 UPR, the maximum value of relative error is 17 %. This is the accuracy that lets to apply developed system in measurements under industrial conditions.

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