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INFLUENCE OF MEASUREMENT STRATEGY ON THE VALUE OF CYLINDRICITY

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Abstract: Never-ending growth of market`s demands causes necessity to control not only geometric dimensions but also complex character of form deviations. Simultaneously, reduction of both costs and working time of production process is expected. What is more, shortening of inspection time need to be considered.

The aim of the paper is to present research on the influence of measurement strategy on correctness of cylindricity determination. Recommendations on proper selection of measurement strategy with taking into consideration the birth – cage method, methods of generatrix lines and roundness profiles of elements with different character of cylindricity are displayed.

Presented recommendations allow to use measurement equipment effectively by minimization of measurement time with respect to its metrological correctness.

Keywords: form deviation, cylindricity, measuring strategy,

1. INTRODUCTION

The development of the design and computer systems to its support is continuous. There still occur new construction materials that allow to the design and manufacture products of very different shapes and properties [1, 2]. At the same time, despite the strong development of new ideas, many constructions are based on traditional approaches. One of these elements are cylindrical connections - the shaft and the hole.

In many cases, elements type of shaft - hole are part of responsible resting or motor connections. Example, at the gudgeon pin, shaft - bearing connection or items such as smoothing rolls. Both the responsibility and the importance of these connections are confirmed with the fact that the control of components type of shaft – hole become one of the basic measurement task performed by the measurement chamber in the industry (up to 80% of all tasks) [3, 4].

The constant need to reduce manufacturing cost and time of manufacturing components goes hand in hand with the search for quick and metrologically correct measurement methods. The possibility of shortening the inspection time only by change in the measurement strategy is particularly desirable because it do not generate additional costs for the entrepreneur [5].

2. CYLINDRICITY

Form deviation is a measure of an actual deviation from its nominal form [6]. This is a set of periodically repeating irregularity of a surface which are characterized by the ratio of the distance between irregularities to their depth that takes value higher than 1000 (formula 1).

$$\frac{\text{distance between irregularities}}{\text{depth}} > 1000 \quad (1)$$

According to ISO 1101: 2004 [6], form deviations are:
- Straightness,
- Flatness,
- Roundness,
- Cylindricity,
- The form of a determined outline,
- The form of a determined area.

The actual form of the hole and the shaft can be described by a cylindricity deviation. It consists of the relative change in diameter of the cylindrical object along its center line, roundness deviation determined in its various sections and noncentricity of the contours roundness according to associated (nominal) axis of the object. Cylindricity deviation therefore can be divided into three groups [8]:

Deviation of the center line – the axis of the object which is nominally cylindrical is a curve (2D or 3D), but roundness profiles (cross sections) of the object are circular and have a constant radius. The typical deviation of this kind is convex (Fig. 1).

Radial deviation – all roundness profiles (cross sections) of nominally cylindrical object are circular and concentric (their centers are on the element`s axis), but their diameters change. Typical examples are conicity or barrel shape (Fig. 2).

Deviation of roundness profiles - cross-sections of nominally cylindrical element have the same form and dimensions, but have a roundness deviation (Fig. 3).

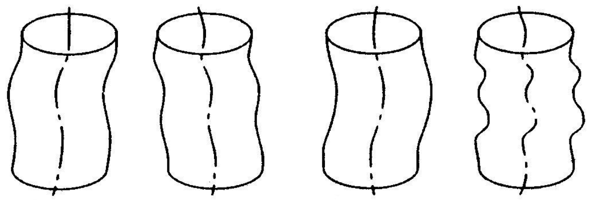

Figure 1 Examples of the deviation of the center line on cylindrical elements [8]

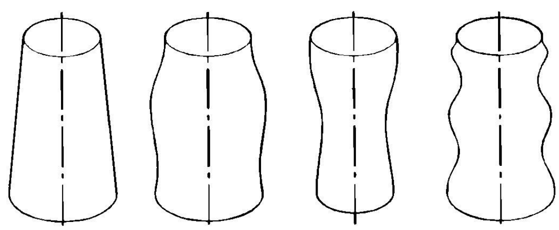

Figure 2 Examples of the radial deviation on cylindrical elements [8]

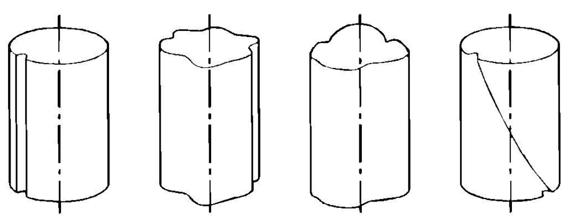

Figure 3 Examples of the deviation of roundness profiles on cylindrical elements [8]

The specific and the most common models of cylindricity deviations that appear in the industry are: a conicity, a barrel shape and a saddleback distortion. These are deviations of the lateral section and can be defined as follows [6]:

- Conicity – form of deviation resembles a cone. The diameter of cross section changes proportionally on following sections, so that generating lines are a straight, but non-parallel.
- Barrel shape - cross sections change in a way that extreme cross sections have smaller diameter than the middle one. Generating lines of actual cross sections are convex curvilinear.
- Saddleback distortion - cross sections change in a way that extreme cross sections have larger diameter than the middle one. Generating lines of actual cross sections are concave curvilinear.

Due to both the complexity of machining processes and errors of its executing the actual cylindrical surface is in most cases compound from all those forms of cylindricity deviation with different levels of occurrence (Fig. 4) [8].

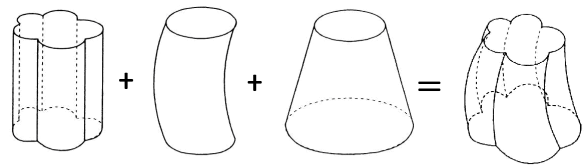

Figure 4 Example of different cylindricity compound [8]

3. MEASUREMENT OF CYLINDRICITY

Cylindricity can be measured using two methods: reference and non-reference one (measurement of differences in radius).

The reference method includes two-point, three-point and n-point measurement (Fig. 5). Measuring devices are relatively simple. This allows for fast and efficient measurements at low cost.

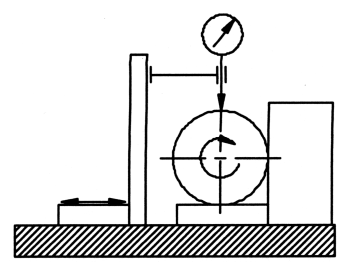

Figure 5 Measurement with reference method

Measurement with difference in radius methods can be divided into four groups - the measurement on the device with: centre points, a rotary table (Fig. 6), with a rotating spindle and coordinate measuring machines. These methods allow to measure with greater accuracy than non - reference methods and allow to automate the measurement process. However, this absorb larger financial resources on measuring equipment.

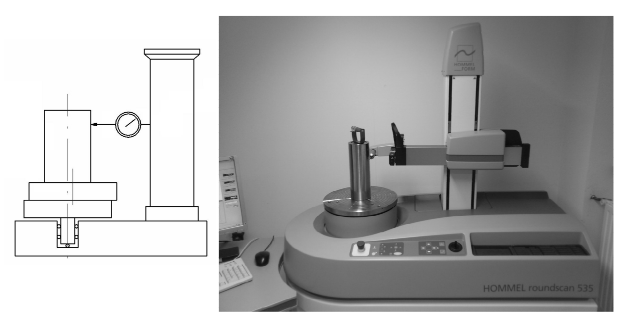

Figure 6 Measurement with non – reference method.

Cylindricity deviations can be measured in accordance with one of five measurement strategies: roundness profiles, generatrix lines, bird cages, helix and random points (Fig. 7) [9, 10].

Most commonly used methods are roundness profiles, generatrix lines, and their combination which create bird cage method. The paper presents research conducted for these three measurement strategies. Each cylinder was measured on longitudinal and cross sections. Calculations and analysis of results were done for all three strategies.

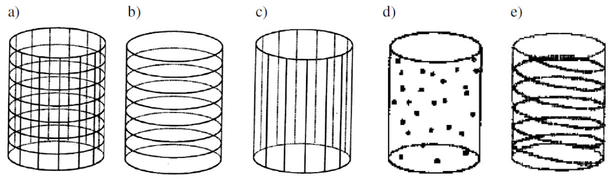

Figure 7 Strategies of measuring cylindricity:
a) bird cage, b) roundness profiles, c) generatrix lines,
d) random points, e) helix [9, 10].

In order to demonstrate the impact of the measurement strategy on the accuracy of determining cylindricity deviation, the same element was measured with each strategy and with a varying number of the measurement - starting from 3, and ending on 16 generating lines and / or roundness profiles.

4. RESULTS

Research was performed using specialized device for the measuring form deviations Hommel-Etamic Roundscan 535 (Fig. 6). Firstly, budget of the uncertainty was estimated, which for cylindricity deviation measurement is U_{95} = 0.2 µm. The tests were conducted for various model of cylindricity deviations: barrel shape, saddleback distortion, conicity, ovality and three – lobbing. What is more element with combination of these deviations were tested. The paper presents examples of research results.

Research began with the model cylinder with no specific form of cylindricity. The value of the form deviation was CYL_t = 1.2 µm. Obtained results are shown in the chart - Figure 8

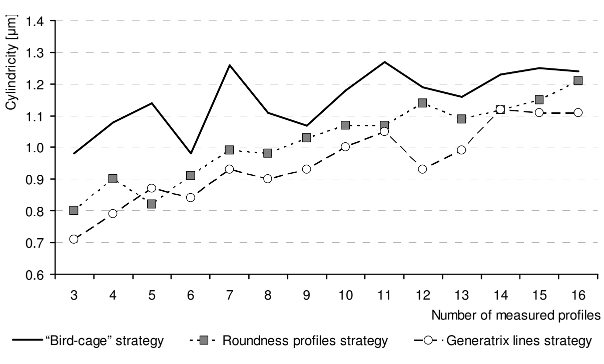

Figure 8 Influence of the number of measured profiles on cylindricity of the master cylinder.

On the basis of obtained data we can conclude that with increasing number of sections the value of cylindricity is raising. The change of cylindricity deviation is 0.2 µm for the bird cage strategy and 0.4 µm for the other two strategies .

The second cylinder had only the roundness profile deviation - it was the three – lobbing (Fig. 9). Acquired information led to the conclusion that in this case, the cylindricity deviations for both methods of bird cage and of roundness profiles are stable regardless of the number of measured sections. For the strategy of generatrix lines the situation is decidedly different. A small number of sections does not allow to properly detect the cylindricity deviation. The situation is adequate to measure the deviation of the roundness on the CMM with a small number of points [11, 12]. Not before the outline is described with larger number of generatrix lines (in this particular case 12), determined cylindricity deviation is adequate to the actual value.

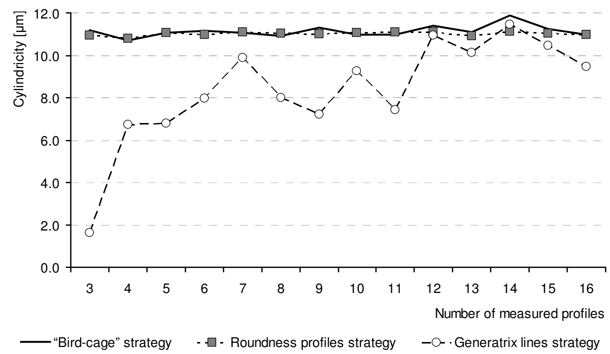

Figure 9 Influence of the number of measured profiles on cylindricity of the cylinder with a 3-lobbing roundness profile deviation.

Measurement of conical element derived the value of cylindricity deviation that remains practically constant for different number of sections. However, interesting phenomenon can be observed when measured component has saddleback or barrel deviation (Fig. 10).

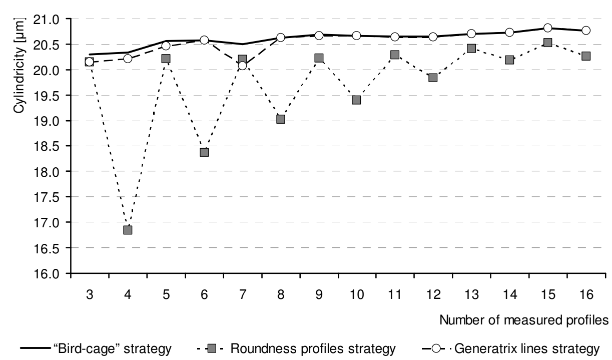

Figure 10 Influence of the number of measured profiles on cylindricity of the cylinder with a barrel shape deviation.

Analysis of the measurement data shows that the value of cylindricity deviation is almost constant for the bird cage and the generatrix line strategy, regardless of the number of sections. Nevertheless, measuring with roundness profiles resulting in significant differences in the value of deviation for measured items. In the case of an odd number of cross sections, the middle and extreme sections present the greatest difference, which in fact is the cylindricity. In the case of measurement with an even number of sections, the middle section is skipped, and so it is not possible to detect the extreme deviation. This phenomenon is suppressed with the increase in the number of sections (Fig. 10).

In the next step of research, when verifying the impact of the strategy of measuring cylindricity items with a single character of form deviation had accomplished, investigations for elements with superposition of form deviation character were started. Figure 11 presents results of measuring the element with the complex deviation – ovality and barrel shape.

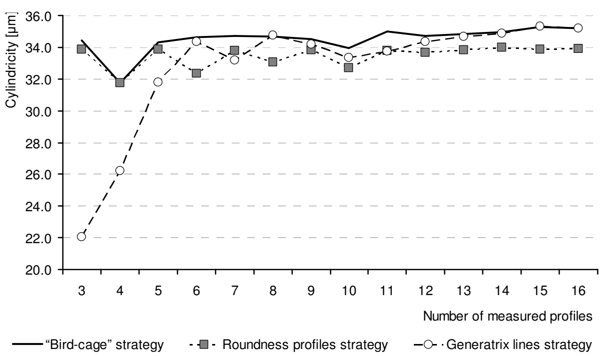

Figure 11 Influence of the number of measured profiles on cylindricity of the cylinder with a complex (ovality and barrel shape) form deviation.

On the basis of research it can be concluded that the value for both strategies the bird cage and roundness profiles are constant regardless of the number of the measurement. It can be also observed changes in the deviation of 4 measurements, which does not reflect the actual value of deviation. Simultaneously, much smaller value of cylindricity deviation measured with the use of 3 or 4 generatrix line were noticed. As in discussed measurement of three - lobbing - creating a small number of generatrix lines causes far worse representation of the actual cylindrical surface. As a result, lower value of the cylindricity is determined.

4. CONCLUSIONS

Measurement of the cylindricity deviation is a task frequently encountered in industry. The increase in requirements among customers makes form deviation one of the basic parameter next to the geometry dimension that need to be monitor. Therefore, it is necessary to seek ways of effective using the measuring device. Effective use in the sense of the shortest possible time of measurement but with maintaining the measurement uncertainty at the required level.

Presented research reveal that the best measurement method is the bird cage. It allows, in each cases, to obtain the highest value of cylindricity - that is the worst variant. The roundness profile method allows to obtain similar values to the results from the bird cage method. Nevertheless, there had been cases in which the measurement by this method did not provide unequivocal results. An example is the measurement of the element with barrel shape deviation (Fig. 10). The alternative in this case is a measurement with an odd number of roundness profiles. The measurement of cylinder with the method of generatrix profiles may give results saddled with the biggest value of error. Derived values – especially for a small number of sections - differ significantly from those obtained with other strategies.

To conclude, the optimal solution is to use the bird cage method. However, due to shortening the time it is proper to measure with roundness profiles method using on condition that the number of roundness profiles is odd.

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