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INFLUENCE OF THE NUMBER OF POINTS ON THE EVALUATED ELEMENT WHEN MEASURING ON CMM

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Abstract

Coordinate measuring machines (CMMs) have been a major advance in the field of engineering measurement in recent decades. They were constructed based on the need to measure complex shaped parts in the automotive and aerospace industries. The rapid development of CMMs is based on the need for increasingly accurate dimensional control. On average, every 10 to 15 years, manufacturing accuracy increases by one level of IT. That is why it is necessary to constantly improve and streamline measurement methodologies.

The article describes a test that focuses on streamlining the CMM setup in the contact measurement process. The paper deals with the influence of the number of points on different evaluated elements when changing the size of the measured part. The test results will be used to make the measurement plans for measurements in the Metrology Laboratory of the University of West Bohemia in Pilsen more effective.

Keywords: CMM points; rotating head; statistics; measurement plans; calibration rings.

1. Introduction

In view of the ever-increasing demands on the functional properties of products, more complex production programmes are needed and great emphasis is placed on production, which must be constantly refined and streamlined. This is not only true for the production of parts, but it is also pushed on the field of metrology in order to make the activity more efficient and more precise. There are many types of gauges on the market for measuring the shapes and other required properties of the manufactured products. There are gauges that measure in one axis (e.g. callipers), in two axes (e.g. workshop microscopes), or in three axes. The latter are called Coordinate Measuring Machines (CMMs) [3].

The main function of a CMM is the comprehensive measurement of the workpiece, i.e. measuring its actual shape, comparison with the desired shape and evaluation of metrological parameters such as size, shape, etc. [6] It follows that CMM is a very frequently used machine for quality control of geometric tolerances of products. Due to the abundance of general shaped surfaces, CMM is widely applied in the measurement and quality control of general shaped surfaces. With its wide range of applications, CMM is a versatile quality control device while maintaining high productivity.

The article describes and evaluates the test, which aims to map the influence of the number of points on the measured values of selected test elements, because the more information we have about this area, the more accurate and efficient our measurements can be. The measurement procedures in the Metrology Laboratory of the University of West Bohemia in Pilsen will be modified and streamlined based on the results of the test.

2. Description of the CMM machine

The CMM is a measuring system that includes tools for moving the system of probes with the ability to determine the spatial coordinates of the workpiece surface. Among the most important features of the CMM are the movable machine construction, the encoder system, the measuring head with the stylus and the measuring software. [5], [8]

The article mainly focuses on the measuring head area with contact measurement. The sensing head and contact form the connection between the machine and the part to be measured. It is used to evaluate the position of the points captured on the workpiece relative to the CMM coordinate system. Probe systems usually refer to the number of axes in which they can operate. They are divided into linear (1 D), planar (2 D) and three-dimensional (3 D) operating systems. [4], [6]

The sensor mounting head can be fixed or rotatable. A fixed head cannot be converted into a rotating head, but a rotating head can be fixed.

3. Experiment description

A rotary probe head was used in the test, as shown in Fig. 1. It was fitted with a ruby ball stylus with a diameter of 1.5 mm Fig. 2 [10]

Fig. 1. Rotary probe head

Fig. 2. Ruby ball stylus

For the simulation of the real part, the attached ring gauges with 3 nominal dimensions (diameters of 16; 50; 90 mm) were used. They are marked in the test as small - medium - large diameter, see Fig. 3.

Fig. 3. Gauges

The following parameters were evaluated on each gauge (Fig. 4.)

- Diameter of the gauge at two depths
- Circularity of the gauge at two depths
- Cylinder diameter
- Cylindricality

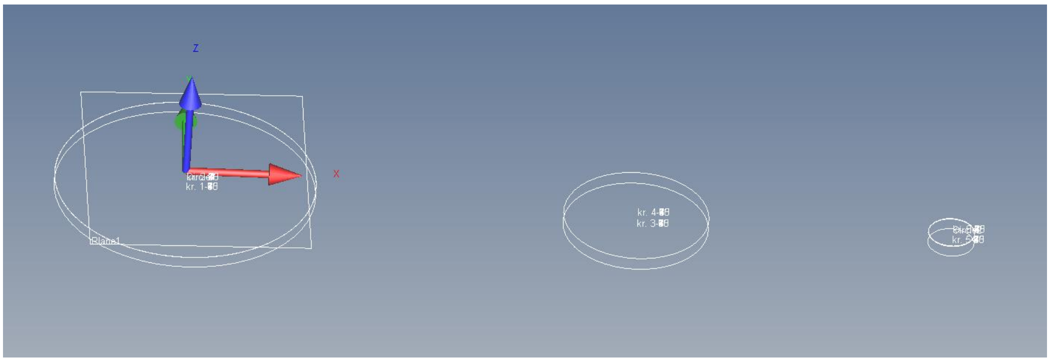


Fig. 4. Diagram of the experiment

When setting the test conditions, the mathematical definition of individual measured elements was used. For a circle on the basis of the mathematical definition, we need at least 3 points not in one straight line to construct a ring. To assemble the cylinder, it is necessary to know at least 6 points lying in at least two planes. [7] Therefore, based on this knowledge, the tables for the number of points tested were set as follows, see Table 1.

Number of points to construct a ring	3, 4, 6, 7, 8, 15, 50 points
Number of points to construct a cylinder	6, 8, 12, 14, 16, 30, 100 points

Table. 1. Number of points required to construct a ring and a cylinder

The rings were measured in two cross sections. All measurements were performed in five repetitions. All measurements were made in a clockwise direction.

4. Data analysis

When analysing the data, it was divided into appropriate categories (average at two measuring points, roundness, cylindricality, cylinder diameter), tested for normality in the minitab program. All measurements confirmed normality.

Subsequently, the standard deviation of each category was calculated to determine the optimum score.

Number of element points	3	4	6	7	8	15	50
Diameter 1	0.00110	0.00162	0.00266	0.00150	0.00228	0.001598	0.001498
Diameter 2	0.00120	0.00162	0.00166	0.00180	0.00208	0.00198	0.00198
Cylindricality 1	0.00132	0.00146	0.00273	0.00288	0.00191	0.00195	0.00109
Cylindricality 2	0.00125	0.00161	0.00173	0.00188	0.00215	0.00205	0.00199

Table. 2. Table with a result from standard deviation

Number of element points	6	8	12	14	16	30	100
Cylinder average	0.00121	0.00160	0.00167	0.00183	0.00221	0.00200	0.00199
Cylindricality	0.00125	0.00168	0.00163	0.00182	0.00215	0.00201	0.00201

Table. 3. Table with a result from standard deviation

Tables 2 and 3 show changes in standard deviations for the individual elements measured. In our case, as can be seen, always at one moment the standard deviation starts to stagnate and keep to almost the same value. [11] Which indicates that at this point the number of scanned points will disappear and the effect of the applied stylus begins to enter the measurement, as described in article 2. [9]

In the next step we attempted to refute or confirm the findings of the previous analysis of standard deviations. Therefore, to perform the point dependence calculation, the analysis was performed using the one-way ANOVA method, see article 1 for a description of the method.

4.1. Example of one-way ANOVA calculation

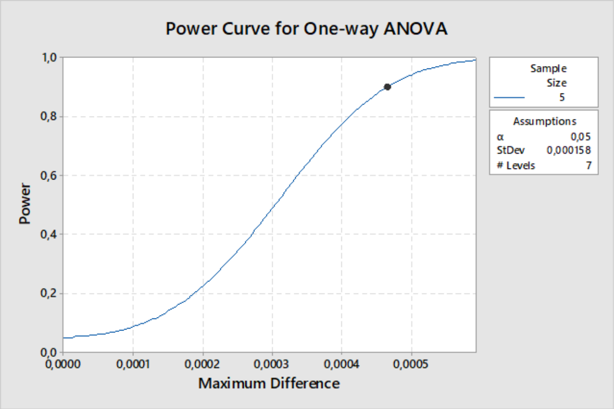
An example for the ring diameter parameter in the top position (position 1) can be seen here. Where we decided to proceed using one-way ANOVA, whether the measured number of repetitions are sufficient or not. [12] If the value (maximum difference) in this test is below 0.05, the number of repeated measurements is sufficient for us at this time.

The evaluation was represented not only numerically, but to facilitate orientation in the problem, graphs were plotted. Graph 1 shows the calculated results in graphical form.

α = 0.05
Assumed standard deviation = 0.000158
Factors: 1
Number of levels: 7

Results

Sample Size	Power	Maximum Difference
5	0.9	0.0004654

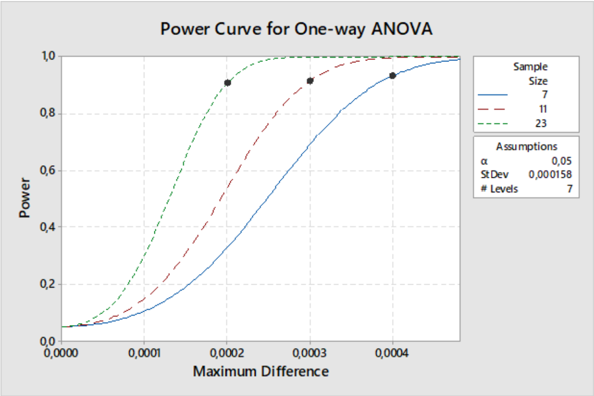


Graph. 1. One-way ANOVA for diameter in position 1

The next step was to verify whether the measured number of repetitions is sufficient using the test - *Test Strength* which predicts how the value of the maximum deviation would change when the number of repetitions of measurements are increased.

Results for other maximum identifiable difference values

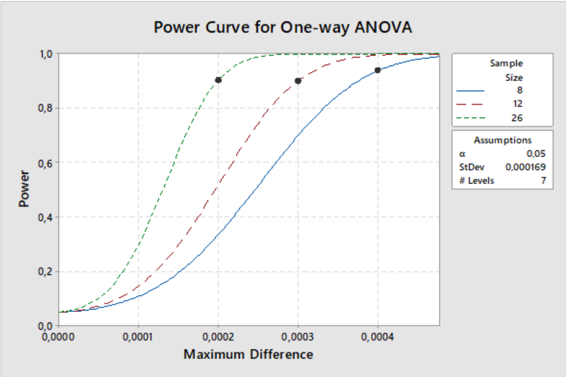
Maximum Difference	Sample Size	Target Power	Actual Power
0.0002	23	0.9	0.905156
0.0003	11	0.9	0.913106
0.0004	7	0.9	0.931793



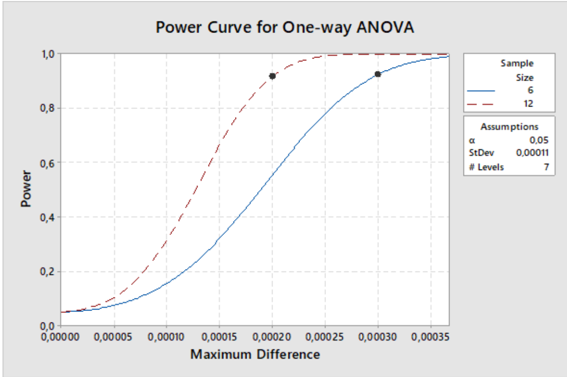
Graph. 2. Result of test test strength-diference value

As can be seen in Graph 2, changing the number of repetitions of measurement and run time, one repetition (1.5 hours) is not worth it. When increased by 2 repetitions, we deviate only 0.1 from the accuracy of our calculation, which is the minimum difference in our test.

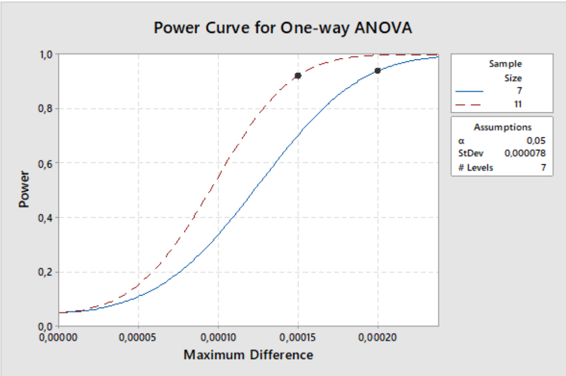
This calculation was performed for all parameters and based on the results (see graphs 3 to 7), it was determined that 5 repetitions are sufficient to test the effect of the number of points on the measured elements.



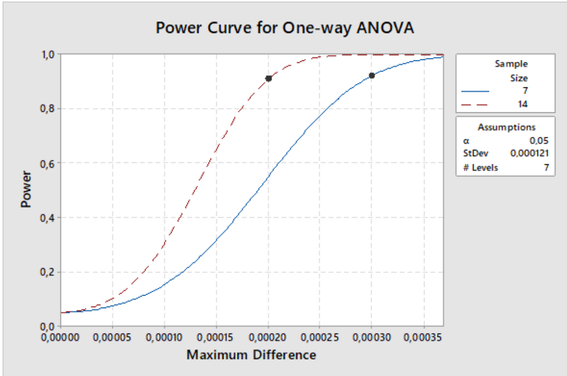
Graph. 3. For diameter in position 2



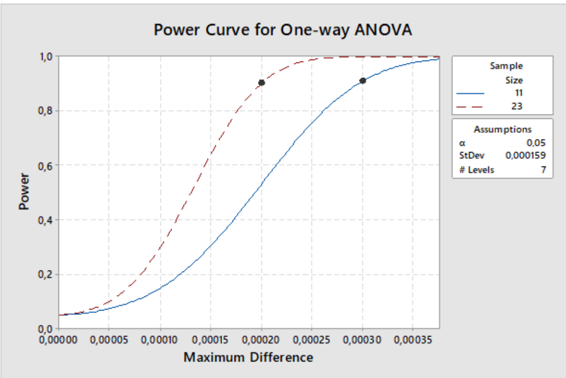
Graph. 4. For cylindricality in position 1



Graph. 5. For cylindricality in position 2



Graph. 6. For cylinder diameter



Graph. 7. For cylindricality

When we verified that the number of repetitions that were performed were sufficient, we proceeded to analyse the effect of the number of points on the measured element. Below is an example of this analysis on the cylindrical element.

4.2. Analysis of cylindricality

The multi-variate ANOVA was used for the analysis. The evaluation was performed separately for each diameter (gauge) separately. However, given that both the evaluation for individual sizes of standards and the evaluation as a whole are important for us, cumulative evaluation was subsequently performed.

ANOVA table for large diameter

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Number of points	6	0.000002	0.000000	155.30	0.000
Error	28	0.000000	0.000000		
Total	34	0.000002			

The p-value is lower than the significance level of 5%. We reject the null hypothesis that the average values of cylindricality are the same for any number of points. The values therefore depend on the number of points used. This confirms our assumption from the previous analyses.

Based on this confirmation, a mathematical model has been compiled that predicts how much the difference will be when using different points. This model works with over 96% accuracy. The model is shown here in the form of several successive graphs, see Fig. 5, not as a mathematical notation that needs to be verified in the future.

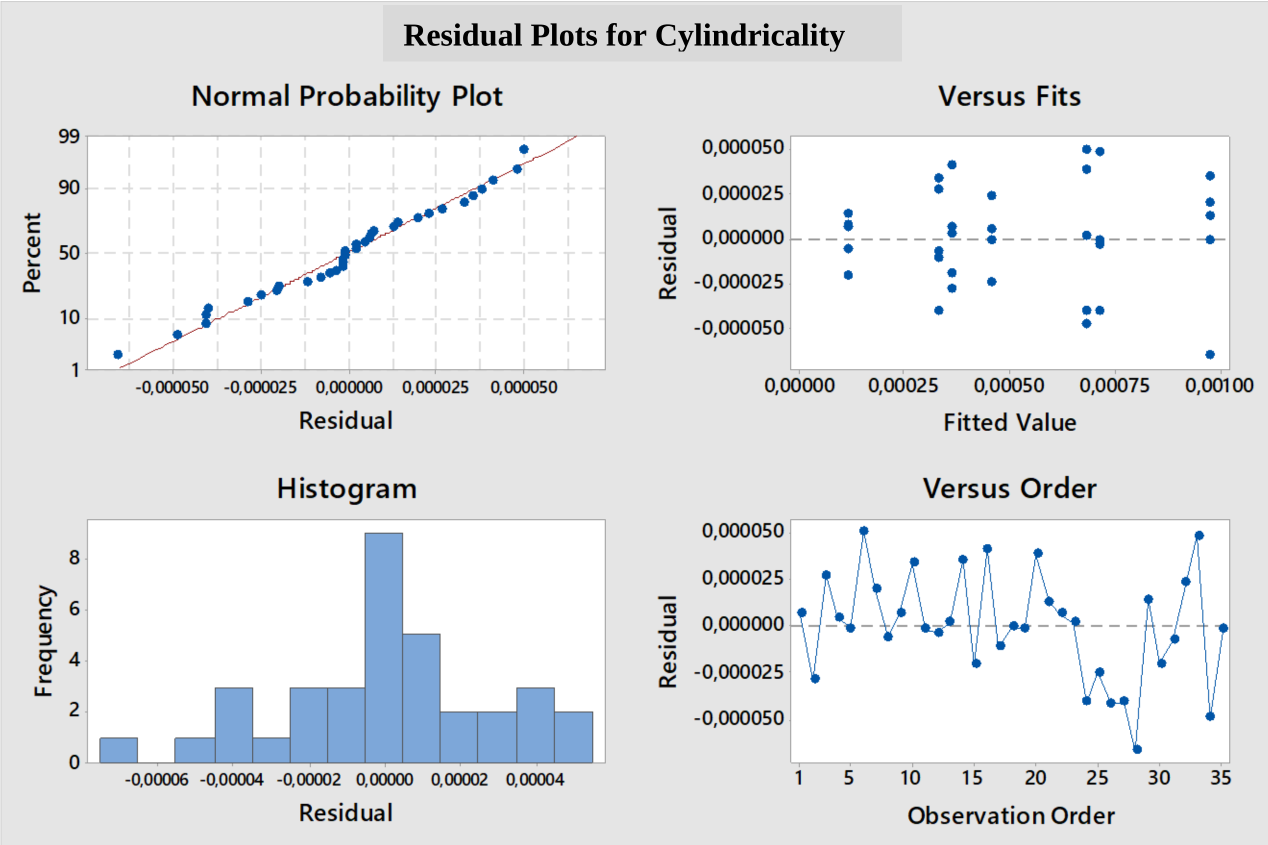


Fig. 5. Graphic representation of the model

Model properties

S	R-sq	R-sq(adj)	R-sq(pred)
0.0000457	97.08%	96.46%	95.44%

Subsequently, on the basis of this calculation and the combination of the results obtained from all three rings, we created a summary model and a summary graph describing the effect of the number of points on the achieved results, regardless of the size of the measured element.

The graph can be seen in Figure 4 which describes the effect of the number of points on the measured values of the cylindrical element. As can be seen, from 30 points onwards the value in the graph is almost constant, and therefore we can assume that from there the effect of the number of points for measuring cylindricality using point measurement is insignificant.

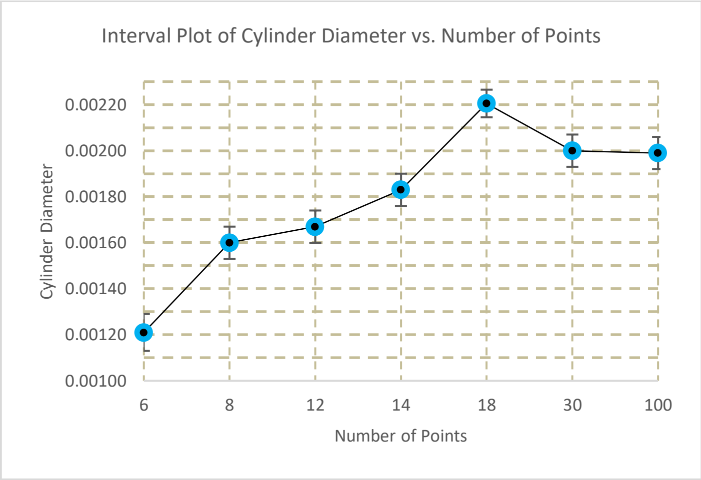


Fig. 6. Interval plot of cylinder diameter vs. number of points

The same evaluation system was performed for the remaining elements evaluated within the test. Because the results were almost identical for the diameter at positions 1 and 2 and the circularity at positions 1 and 2, one summary graph was created.

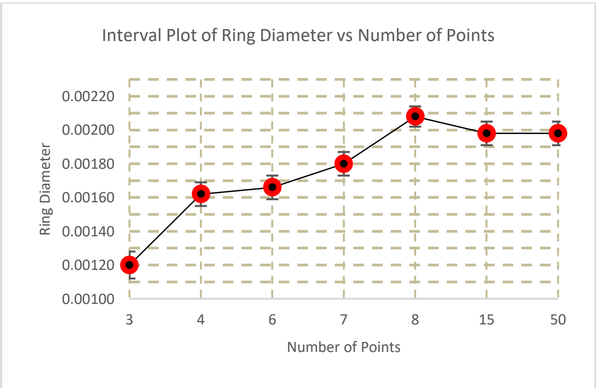


Fig. 7. Analysis of Diameter

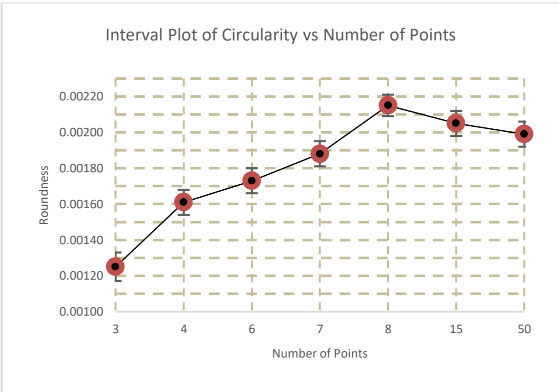


Fig. 8. Analysis of Circularity

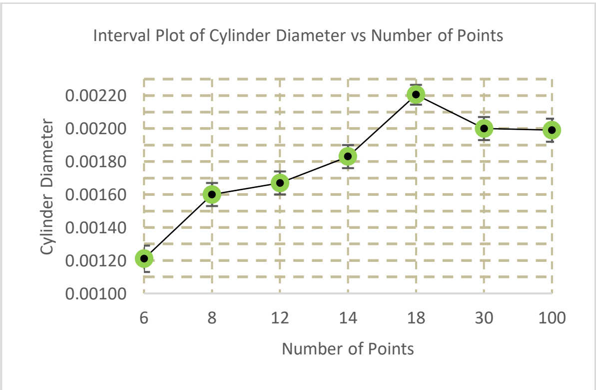


Fig. 9. Analysis of cylinder diameter

Looking at the graphs in Figures 7 to 9, it can be stated that for the circularity and ring diameter, at least 15 points should be used to ensure the accuracy of the measurement, and at least twice as many for cylindricality and cylinder diameter, i.e. at least 30 points.

However, it should not be forgotten that in this test, the limit for the number of points on the ring was set at only 50 points and on the cylinder 100 individual points were measured. Based on our results, it would be good to verify the test with at least one test which would include a larger number of scanned points.

5. Conclusion

The main function of coordinate measuring machines is the complex measurement of a workpiece, thus measuring its actual shape in comparison with the required shape and evaluation of metrological parameters such as size, shape, etc. It follows that CMM is a very widely used machine for quality control of products in terms of dimensional and geometric tolerances. Due to the abundance of general shaped surfaces, CMM is widely employed in the measuring and quality control of general shaped surfaces. With its wide range of applications, CMM is a versatile quality control device which maintains high productivity. The paper describes a test that focuses on streamlining the CMM setup in the contact measurement process. The paper deals with the influence of the number of points on different evaluated elements when resizing the measured part. And based on these tests we will make the measurement plans used for measurements in the Metrology Laboratory of the University of West Bohemia in Pilsen more effective. The rotating sensing head was fitted with a ruby ball with a diameter of about 1.5 mm. In order to simulate the real part, the attached ring gauges with three dimensions were used: small - medium - large diameter. The parameters of the diameter of the gauge at two depths were evaluated on each gauge, the circularity of the gauge at two depths, the cylinder diameter and finally the cylindricality. Individual elements were repeatedly scanned using different numbers of points based on mathematical definitions of the elements. The circles were measured in two sections. All measurements were performed in duplicate 5 times. All measurements were made clockwise in the test. Subsequently, the data were subjected to a detailed mathematical analysis, which led to the finding that for circularity and ring diameter, at least 15 points should be used to ensure the accuracy of the measurement in the minimum measuring time. At least twice the number of points are required for cylindricality and cylinder diameter, i.e. at least 30 points to ensure optimum evaluation of the element. However, it should not be forgotten that in this test, the limit on the number of points on a ring was set at only 50 points and on the cylinder 100 points. Based on the results, it would be good to verify the test on at least one test which would include a larger number of scanned points.

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