GRANT journal
ISSN 1805-062X, 1805-0638 (online), ETTN 072-11-00002-09-4
Vol. 9, Issue 1
EUROPEAN GRANT PROJECTS | RESULTS | RESEARCH & DEVELOPMENT | SCIENCE

Influence of the number of points on the contact scanning process during measuring on the CMM

Dana Kubátová[1]
Aneta Kaufnerová[2]
Jan Kutlwašer[3]

[1] University of West Bohemia in Pilsen, Univerzitní 8, 301 00 PILSEN, CZ, kubatova@rti.zcu.cz
[2] University of West Bohemia in Pilsen, Univerzitní 8, 301 00 PILSEN, CZ, akaufner@rti.zcu.cz
[3] University of West Bohemia in Pilsen, Univerzitní 8, 301 00 PILSEN, CZ, kutlis@rti.zcu.cz

Grant: SGS-2019-008
Name of the Grant: Research and development for innovation in the field of manufacturing processes – Technology of metal cutting III
Subject: JR - Other machinery industry

Abstrakt Coordinate measuring machines (CMMs) have been a major advance in the field of engineering measurement in recent decades. They were designed 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 purpose of the tests performed and described in this article is to map the effect of the number of points when measuring the CMM by contact scanning. The task of the tests was to find the optimal setting of the machine while constantly maintaining the accuracy and repeatability of measurements. If the optimal number of points is found, the results of the experiment will lead to the optimization of the measurement processes on the CMM.

Key words CMM points, fixed head, contct scanning, statistics, measurement plans, calibration ring

1. INTRODUCTION

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

This article describes and evaluates a test which aimed to map the effect of the number of measuring points on the measured values of the selected elements. Because the more information we have about the measuring process, the more accurately and effectively we can perform the measurements. And based on the results of the test, we can then modify and thus streamline the measurement procedures in the Metrology Laboratory of the University of West Bohemia in Pilsen.

2. DESCRIPTION oF THE MACHINE

A CMM is a measuring system that includes tools for manipulating a system of probes with the ability to determine the spatial coordinates of a workpiece surface. Among the most important features of the CMM are its movable machine construction, the encoder system, the measuring head with the stylus and the measuring software.

This article mainly focuses on the measuring head 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.

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 fixed 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

GRANT journal
ISSN 1805-062X, 1805-0638 (online), ETTN 072-11-00002-09-4 Vol. 9, Issue 1
EUROPEAN GRANT PROJECTS | RESULTS | RESEARCH & DEVELOPMENT | SCIENCE

Figure 1 Sensor head

Figure 2 Sensor contact

The integral ring gauges with 3 nominal dimensions (diameters of 16 mm 50 mm and 90 mm) were used to simulate the real part. They are marked in the test as small - medium - large diameter, see Fig. 3.

Figure 3 Ring gauges

The following parameters were evaluated on each gauge

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

When setting the test conditions, the mathematical definition of individual measured elements was used. The number of points was set as follows, see Table 1.

Number of points to construct a ring	50, 100, 500, 1000, 3000, 5000 points
Number of points to construct a cylinder	100, 200, 1000, 2000, 6000, 10000 points

Table 1 Number of points for a circle and a cylinder

The rings were measured in two cross sections. The measurement was performed using contact scanning. All measurements were repeated five times. All measurements were made in a clockwise direction.

4. DATA ANALYSIS

When analyzing the data, it was divided into appropriate categories (diameter at two measuring points, roundness, cylindricality, cylinder diameter). The data were tested for normality in the Minitab program. Normality was confirmed for all measurements.

Subsequently, in the procedure for determining the optimal number of points, the standard deviation of individual categories was calculated. The standard deviations are used for the initial quick creation to give an idea of how the data behaves.

The number of points in the element	50	100	500	1000	3000	5000
Diameter 1	0.000519	0.000587	0.000524	0.000542	0.000542	0.000572
Diameter 2	0.000560	0.000528	0.000575	0.000573	0.000599	0.000547
Circularity 1	0.001016	0.000615	0.000347	0.001414	0.000484	0.010426
Circularity 2	0.000531	0.000719	0.000488	0.000347	0.001532	0.005635

Table 2 Table with reset of standard deviation

The number of points in the element	100	200	1000	2000	6000	10000
Diameter of cylinder	0.000571	0.000545	0.000591	0.000526	0.000541	0.000564
Cylindricity	0.000706	0.000852	0.011972	0.004158	0.011402	0.016926

Table 3 Table with reset of standard deviation

Tables 2 and 3 show the changes in standard deviations for the individual measured elements. Looking at tables 2 and 3, it is possible to clearly identify trends in the behaviour of the evaluated data. There are two trends, depending on which element is evaluated. The first trend confirms the findings in article 2, which led to the conclusion that 30 points are sufficient to evaluate the average. The second trend indicates that when scanning and evaluating circularity or cylindricity, the points used for the test are probably not sufficient for the correct evaluation of the given elements, due to the fact that their standard deviation is still increasing. This suggests that we will need to test even higher numbers of points in order to evaluate circularity and cylindricity.

4.1 Analysis of circle and cylinder diameters

A multi-factor ANOVA method was used to evaluate the effect of points. The evaluation of each diameter (gauge) was performed separately [5,6]. However, bearing in mind that both the evaluation of the individual evaluated parameters (diameter, roundness, cylindricality,…) and the evaluation as a whole is important for us.

4.1.1 Large diameter–evaluation of element diameter

Here we provide an example of the evaluation of a gauge with a large diameter. The processing and evaluation of the test took place according to the same conditions and procedures as in article 2. The method of evaluation was left the same due to the relevance and possible interconnection of the achieved outputs.

Table 4 shows the results for a one-factor ANOVA method. It can be seen that for the result based on the p-value in the input test, the number of points will not have such a significant effect on the measured values. However, at the same time, this table indicates that our evaluation lacks some other influences that have a significant impact on the achieved results. [6,7,8] This statement is also based on the value of the accuracy of the prediction model, which is very low; the value of R-sq is only 6%.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Numberofpoints	5	0.000000	0.000000	0.32	0.896
Error	24	0.000003	0.000000		
Total	29	0.000003			

S	R-sq	R-sq(adj)	R-sq(pred)
0.0003256	6.25%	0.00%	0.00%

Table 4 Table with ANOVA result

Based on this finding, the measured values were displayed in a graph (Fig. 4) where the effect which was neglected during the initial evaluation, is very clearly visible. This is the effect of the measuring loop (stepped arrangement of points).

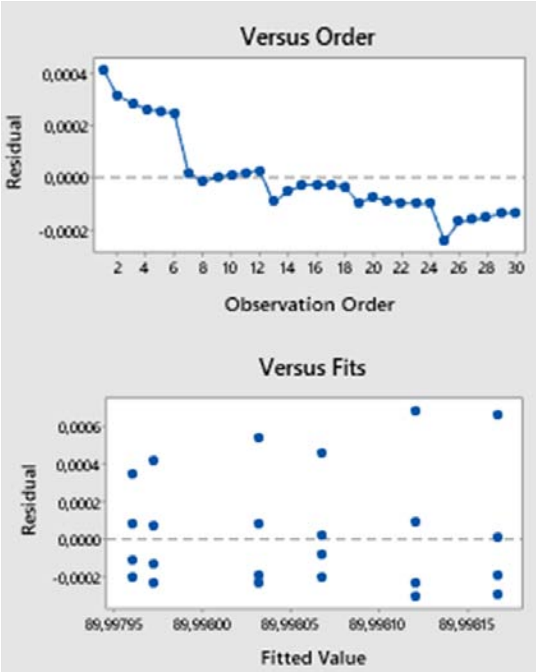


Figure 4 Results of graphical representation of data

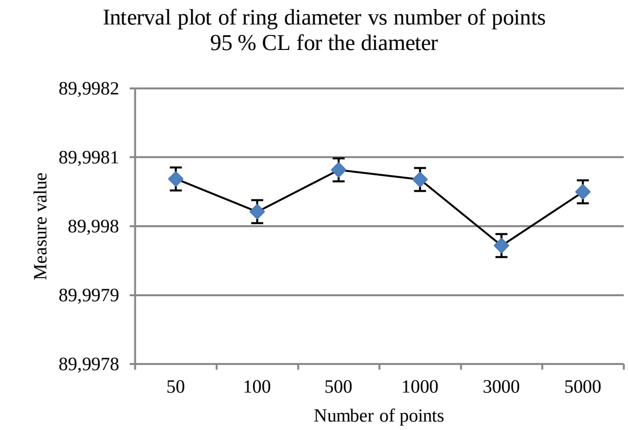
Based on the finding that the effect of the loop enters the measurement, multi-factor ANOVA was used instead of the one-factor ANOVA method. An evaluation of the results could then be performed based on this method.

Looking at Table 5 with the results of the multi-factor ANOVA method, it can be stated that the number of points does not affect the achieved values. [1,9,10] However, this is true only if the diameter of the part is evaluated. What cannot be overlooked, however, is the need to correct the results when the measurement is performed in a loop. All this can be stated on the basis of a model that works with an accuracy of 94%.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	9	0.000003	0.000000	36.17	0.000
Numberofpoints	5	0.000000	0.000000	4.32	0.008
Cycles	4	0.000002	0.000001	75.99	0.000
Error	20	0.000000	0.000000		
Total	29	0.000003			

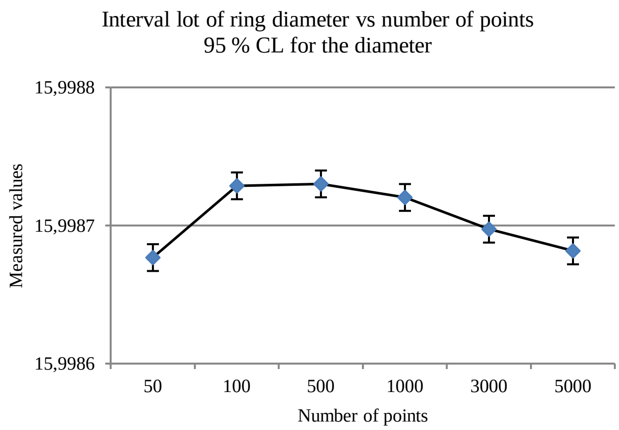
Table 5 Table with ANOVA reset with new source

For confirmation, the evaluation was plotted in a graph (Graph 1). Here, it is possible to clearly identify and state that the number of points has almost no effect on the measurement.

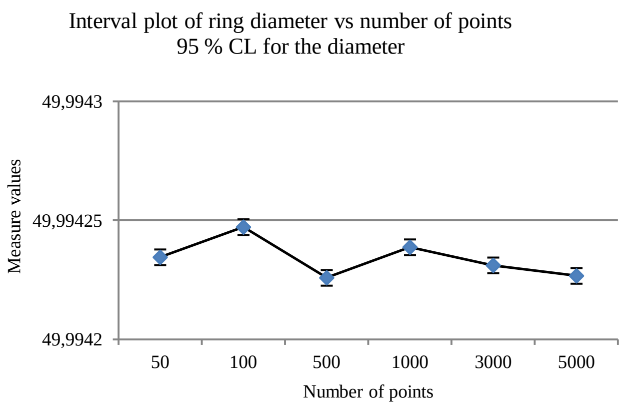


Graph 1 Interval plot of ring diameter vs number of points 95 % CL for the diameter

The same is true if we look at the graphs for evaluating the diameters for the small and medium gauges. See graphs 2 and 3.



Graph 2 Interval plot of ring diameter vs number of points 95 % CL for the diameter



Graph 3 Interval plot of ring diameter vs number of points 95 % CL for the diameter

4.1.2 Large diameter - evaluation of roundness and cylindricity

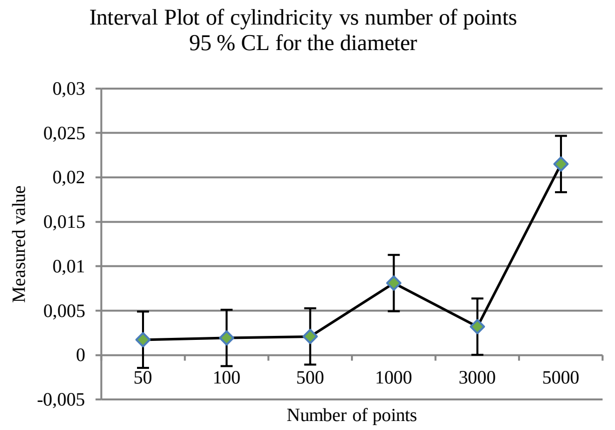
However, it is different if we look at the evaluation of roundness or cylindricity. Here, a multi-factor ANOVA method was also used for evaluation. This tells us that the number of points plays a relatively large role in the evaluation of the parameters that describe the shape of the surface.

A model is given for a multi-factor ANOVA for a large diameter. [11] The model clearly shows that the number of points affects the measured results of roundness and cylindricity. Furthermore, the model shows that it is not necessary to make corrections to achieve results when measuring the part in a loop. This can be read from the model with an accuracy that exceeds 91% accuracy.

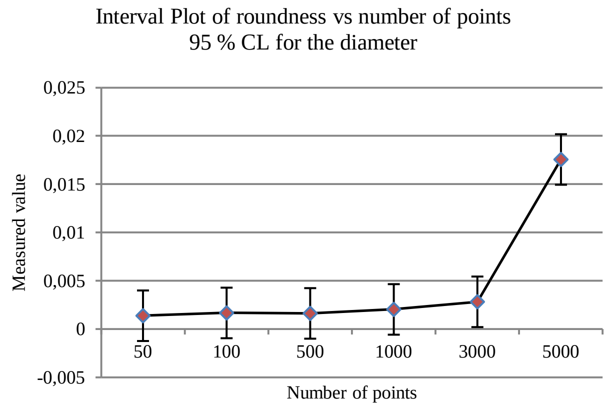
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	9	0.000003	0.000000	32.17	0.000
Numberofpoints	5	0.000000	0.000000	5.32	0.0038
Cycles	4	0.000002	0.000001	67.99	0.006
Error	20	0.000000	0.000000		
Total	29	0.000003			

Table 6 Table with ANOVA result

This statement was also confirmed by the graph plots of the test. Furthermore, it is possible to state on the basis of the graphs that the optimum for measuring roundness or cylindricality was probably not found.



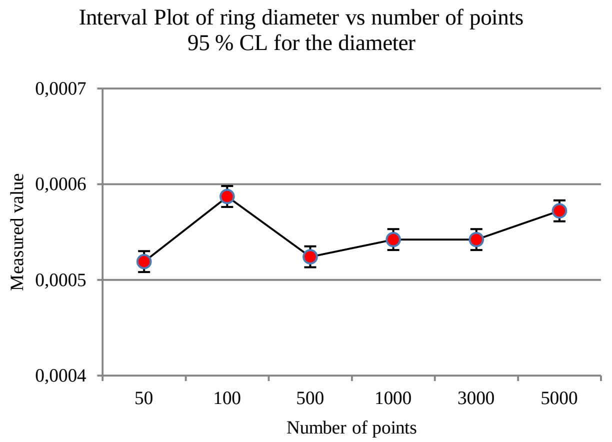
Graph 4 Interval Plot of cylindricity vs number of points 95 % CL for the diameter



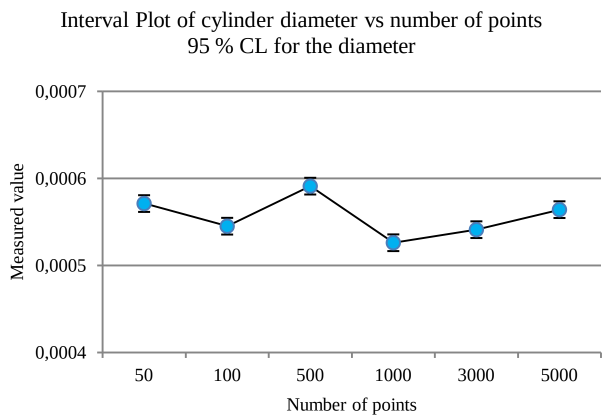
Graph 5 Interval Plot of roundness vs number of points 95 % CL for the diameter

Based on these analyses, the results for all three rings were combined. A summary model and summary graphs describing the influence of the number of points on the results were created, regardless of the size of the measuring element. For easier orientation in the results, first the results for the diameter were compiled and then also for the evaluation of roundness and cylindricality.

For easier orientation, only the graphs of the results from the models are given here. Looking at graphs 6 and 7 for evaluating the diameter of a circle or diameter of a cylinder, it is clear that the measured values are almost constant, regardless of the selected number of points. This is partly confirmed by the assumption from article 2, where the optimal number of points was found for the evaluation of the circle diameter to be 15 points, and for the evaluation of the diameter, 30 points. And here in this test the minimum number of point's was50.

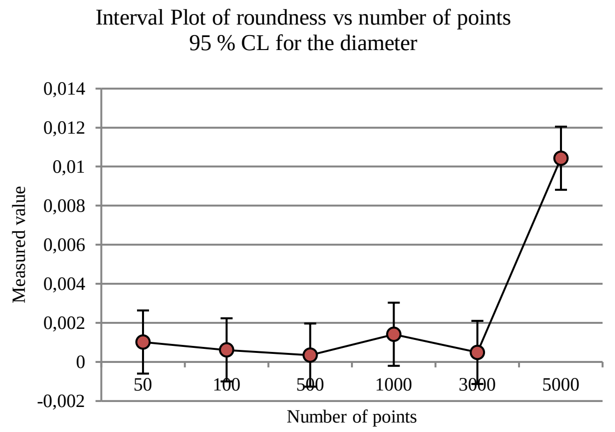


Graph 6 Interval Plot of ring diameter vs number of points 95 % CL for the diameter

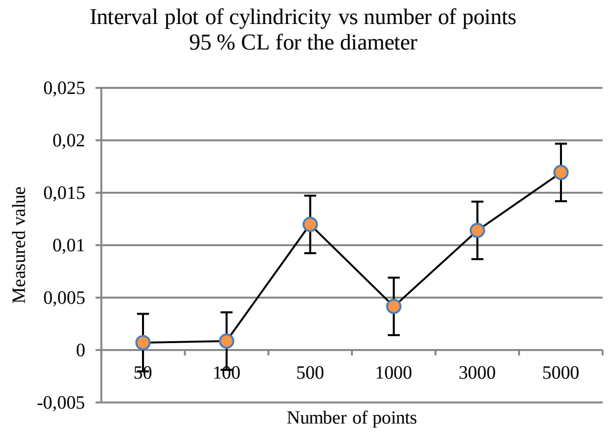


Graph 7 Interval Plot of cylinder diameter vs number of points 95 % CL for the diameter

For cylindricity and roundness, there are different results in graphs 8 and 9. As the interim results suggested, the test is not relevant because the maximum number of 5000 points for a circle and 10,000 points for a cylinder were selected for testing. It is not possible to unambiguously determine the optimal number of points for the evaluation of these elements by contact scanning. Thus, no such number of points was found from which the standard deviation of the measured data would become approximately constant. For the evaluation of roundness, there was a long-term hope that the optimum would be found, but in the last test, the standard deviation flew well above the values that were obtained throughout the test. In the evaluation of cylindricality, this hope of finding the optimum was terminated even earlier. Therefore, based on the data obtained from the tests, an additional experiment is planned, which will focus exclusively on the evaluation of roundness and cylindricality in contact scanning.



Graph 8 Interval Plot of roundness vs number of points 95 % CL for the diameter



Graph 9 Interval plot of cylindricity vs number of points 95 % CL for the diameter

5. CONCLUSION

The main function of coordinate measuring machines is the complex measurement of the workpiece, measuring its current shape, comparison with the required shape and evaluation of metrological parameters such as size, shape, etc. It follows that CMMs are widely used for product quality control, in terms of dimensional and geometric tolerances. Due to the abundant occurrence of generally shaped surfaces, CMM finds many applications in the measurement and quality control of generally shaped surfaces. Thanks to its wide range of applications, CMM is a universal device, enabling quality control, while maintaining high productivity.

The article describes an experiment and its evaluation which focuses on streamlining the CMM settings in the process of measurement by contact scanning. The article deals with the influence of the number of points on different evaluated elements (the diameter of a ring, the diameter of a cylinder, roundness, cylindricality) when changing the size of the measured part. Subsequently, the results of this test will be incorporated into the measurement methodology for using CMMs, which will serve to streamline the measurement plans and processes used for measurement in the Metrology Laboratory of the University of West Bohemia in Pilsen and other metrology laboratories cooperating with this laboratory.

As part of the test, a fixed sensor head was used, which was fitted with a contact with a ruby ball of diameter 1.5 mm. To simulate a real part, ring gauges with three dimensions were used, referred to in the article as ‘small’, ‘medium’, and ‘large’ diameters.

The parameters of the gauge at two depths, the roundness of the gauge at two depths, the diameter of the cylinder, and finally the cylindricality were evaluated on the individual gauges. The individual elements were repeatedly scanned with different numbers of points. Measurements were performed by contact scanning. All measurements were repeated 5 times. All measurements were performed clockwise as part of the test.

Subsequently, the data were subjected to mathematical analysis. This analysis was performed in several consecutive steps. In the first step, the standard deviations of the measured data were calculated. These were used to create an initial view of the data obtained. In the second step, the data were analyzed using the one-factor, or multi-factor ANOVA method. The outputs then confirmed or refuted the initial data.

Based on the results, it can be clearly stated that for the evaluation of the diameter of a circle or cylinder, the optimum number of points really lies on the border of 30 points. However, it is different if we focus on the evaluation of cylindricality and circularity. Based on the results, it is not possible to unambiguously mark the optimum number of points sufficient for relevant measurements. For the evaluation of roundness, there was a long-term hope that the optimum would be found, but in the last test, the standard deviation flew well above the values obtained throughout the test, see Graph 8. For the evaluation of cylindricality, this hope of finding the optimum was terminated even earlier, with a value of 500 points when the standard deviation began to fluctuate significantly. And therefore the optimum was not found here either.

Therefore, based on the data obtained from both tests in this article or in article 2, an additional experiment is already planned, which will focus exclusively on the evaluation of roundness and cylindricality in contact scanning and combine the findings from both tests.

Source

1. STHLE, Lars a Svante WOLD. Analysis of variance (ANOVA). Chemometrics and Intelligent Laboratory Systems. 1989, 6(4), 259 - 272. DOI: doi.org/10.1016/0169-7439(89) 80095-4.
2. Kubatova, D[ana] &Melichar, M[artin] (2019). Influence of the Number of Points on the Evaluated Element when Measuring on CMM, Proceedings of the 30th DAAAM International Symposium, pp.0476-0483, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-22-8, ISSN 1726-9679, Vienna, Austria DOI: 10.2507/30th.daaam.proceedings.064
3. Mayer, J. R. R., Mir, Y. A., Trochu, F., Vafaeesefat, A., &Balazinski, M. (1997). Touch probe radius compensation for coordinate measurement using kriging interpolation. Proceeding softhe Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 211(1), 11-18. doi:10.1243/0954405971516031ZEISS [online]. [cit. 2019-03-15].
4. GHASEMI, Asghar a Saleh ZAHEDIASL. Normality Tests for Statistical Analysis: A Guide for Non-Statisticians. International Journal of Endocrinology and Metabolism [online]. 2012, 10(2), 486-489 [cit. 2020-06-05]. DOI: 10.5812/ijem.3505. ISSN 1726-913X. Available: https://sites.kowsarpub.com/ijem/articles/71904.html
5. JIROUŠEK, Pavel. Eligibility of measurement system in the gearboxes production of Škoda auto a.s [online]. 2012 [cit. 2017-03-08].
6. PERNIKÁŘ J.: Assessment of the competence of control means [online]. [cit. 2016-11-25]. Available from: http://gps.fme.vutbr.cz/STAH_IN FO/31_Pernikar_VUTBR.pdf
7. Płowucha W., Jakubiec W., Wojtyła M.: Possibilities of CMM Software to Support Proper Geometrical Product Verification, Procedia CIRP, Volume 43, 2016, Pages 303-308, ISSN 2212-8271, http://dx.doi.org/10.1016/j.procir.2016.02.124 .
8. Barini M. E., Tosello G. Chiffre d L.: Uncertainty analysis of point-by-point sampling complex surfaces using touch probe CMMs: DOE for complex surfaces verification with CMM, Precision Engineering, Volume 34, Issue 1, January 2010, Pages 16-21, ISSN 0141-6359, http://dx.doi.org/10.1016/j.precisioneng.2009.06.009
9. D. Kubátová, M. Melichar, J. Kutlwašer, Evaluation of Repeatability and reproducibility of CMM equipment, (2017) In Procedia Manufacturing, Volume 13, Pages 558-564, ISSN 2351-9789, https://doi.org/10.1016/j.promfg.2017.09.091.
10. RYAN, P., T., Statistical Methods for Quality Improvement. (2011) Georgia: Wiley, 657 p. ISBN 978-1-118-05811-4
11. Bicova, K[aterina] &Bebr, L[ukas] (2018). Analysis and Dependability of Production Processes for the Automotive Industry, Proceedings of the 29th DAAAM International Symposium, pp.0416-0420, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-20-4, ISSN 1726-9679, Vienna, Austria DOI: 10.2507/29th.daaam.proceedings.061