LOGISTICAL MEASUREMENT STRATEGY ON COORDINATE MEASURING MACHINES AS A TOOL FOR THE REPRODUCIBILITY OF RESULTS

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This paper examines the impact of a selected logistical measurement strategy on coordinate measuring machines for the reproducibility of measurement results. Optimising the reproducibility of measurement results is one of the basic requirements in the process of verifying the quality of components between organisations, workplaces and processes. Selected measurement strategy and logistics selected by the operator of a coordinate measuring machine may be transposed as variability of measurement results because of these parameters. This variability, expressed as the uncertainty of measurement, is a potential source of disparity between the results of individual measurements of the same parameters on machine components. This paper examines the process and the influence of selected aspects of the chosen measurement strategy on resulting uncertainty of measurement and its behaviour in terms of the conditions of reproducibility. Experimental research is based on the use of Taguchi methods of experiment design and more precise MSA (measurement system analysis) tools.

KEYWORDS

measuring machines (CMM), CAD design models, logistical measurement strategy, measurement system analysis (MSA), Taguchi methods of experiment design

1 INTRODUCTION

Globalisation of the free market and the resulting unlimited opportunities to apply components manufactured by a company at one end of the world in the products of another half a world away, exerts ever greater pressure on quality, precision and reliability, as well as on the flexibility of production. Consistent delivery of required level of precision in parts is currently one of the most important tasks in the supply and subcontracting chain logistics process. The continuous development of production technologies, their automation and the use of new methods of production, such as 3D printing, contribute to the fact that the shapes of components are becoming more complex than ever before. Critically, no current technology can produce components with an ideal shape and with functional surfaces that are mathematically identical to CAD design models [Fabian 2014].

Coordinate measuring machines (CMM) play an irreplaceable role due to their precision and flexibility, especially in terms of the verification of products in serial production. The current state-of-the-art permits their installation directly in production. They may be designed as mobile devices which eliminates the issue of creating a special inspection station directly in production. The simplicity of control and provided software make CMM easier to use and reduce their overall cost in the process of inspecting manufacturing processes [Ali 2008].

This experimental research is based on the Taguchi methods of experiment design. These methods are used to experimentally determine the effect of parameters that are the most critical to the observed output of the experiment, and to identify the most appropriate logistical values for these parameters to achieve the desired objective. In such proposed experiments, parameters are called factors and their values are expressed as levels.

Taguchi methods facilitate a reduction in the number of repeated attempts within an experiment with respect to conventional approaches. This reduction is the result of a specially developed table design used for these repetitions called orthogonal arrays. They are essentially used to reduce the number of repeated attempts to conduct an experiment and for simplification purposes when defining combinations of factor levels for individual repetitions. The basic step involves classifying all factors into columns in which their level values are filled in using the specific method for the given array. One of the characteristics of these arrays is that a specific combination of characters in a single row only repeats once. This eliminates the potential for repetition of the same conditions in subsequent attempts within the experiment. Therefore, the conditions for a single attempt within the experiment are recorded in each row. The result is a system able to transparently test the maximum number of effects of multiple factors while minimising the number of repetitions [Dovica 2006], [Bosch 1995].

2 MECHANICAL AND METHODOLOGICAL RESOURCES FOR THE EXPERIMENT

Brainstorming, as a standard tool for creative group problem solving, is used within Taguchi methods. It is performed by all members of the organisations in contact with the experimental process under investigation. The outcome of this brainstorming in the Taguchi methods is a situation where "we know the objective of the experiment, the monitored criteria, factors and their levels, and therefore we are able to propose a complete P-diagram, see Fig.1. Only then can we proceed to the next step and create an orthogonal array".

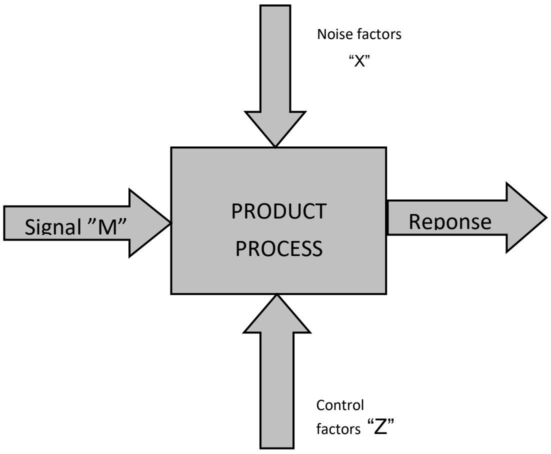

Figure 1. Diagram of parameters (P - diagram)

Measurements were completed on a CMM made by DEA of Italy (Fig. 2) using a standard portal structure with air bearings on all axes. A numbered code indicates the size of the machine. The working table is made of black granite and features an embedded guide rail for the *y* axis. The portal is constructed of a very strong aluminium alloy casting. The same material is used to complete the other moving parts of the tool. The cross beam as the horizontal part of the portal is manufactured using patented "*SLANT BRIDGE*" technology, which uses extruded aluminium alloy to achieve high strength and rigidity. Polyurethane toothed belts dampen vibration and transfer actuator commands from the drives. The drives themselves use DC motors. The *x* axis carriage moves along the horizontal part of the portal and defines the positions of the vertical spindle sleeve working in *z* axis. The guide surfaces of the air bearings are micro-milled with subsequent anodization to ensure a high level of precision and good durability of these guides. The spindle sleeve is pneumatically balanced.

Figure 2. DEA Global Performance CMM

The component measured as a subject of research (Fig. 3) was manufactured as a functional component of an extrusion press to produce biomass pellets. The internal roller is its functional component. Standard class 11 500 steel was used to manufacture the component. The component was machined to the required specifications from a rod-shaped stock material using turning, milling and grinding techniques [Daneshjo 2012], [Král 2014].

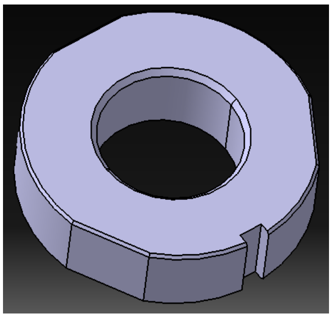

Figure 3. CAD model of the measured component

Cylindrical surfaces are among the most common functional surfaces inspected using CMM equipment. The workpiece complies with the specified tolerances when the tolerance of the actual surface is within the range of tolerances reduced by the uncertainty of measurement. The term tolerance and tolerance range must be defined for better understanding. Tolerance is the name of the linear dimensions that characterises the tolerance range. The tolerance applied to a specific element defines the tolerance range in which this element must be located. The tolerance range is a specification bounded by one or several geometric ideals and precise lines or surfaces [Zakharov 2006].

Cylindrical tolerance, which describes deviations in the investigated surface and is covered in this investigation, is considered a shape tolerance and is defined by the STN EN ISO 1101:2006 standard. This tolerance and other shape tolerances are included in the GPS concept and subject to a separate standard, STN EN ISO 12180-1: 2011 with CY the abbreviation uses in relevant sources (cylindricity). "The tolerance range is defined by two coaxial cylinders.(Fig. 4) When inspecting for shape deviations, the finished surface of the complete cylinder should not exceed the spacing of the two coaxial cylinders" [Feng 2001], [Králik 2011].

The surface of the cylinder is therefore defined by two coaxial cylinders with a radial distance of t_z characterising the tolerance, even though the diameters of these cylinders are not defined. The condition to be met by such cylindricity tolerance is described as follows:

$$CYLt(MZCY) < t_Z$$

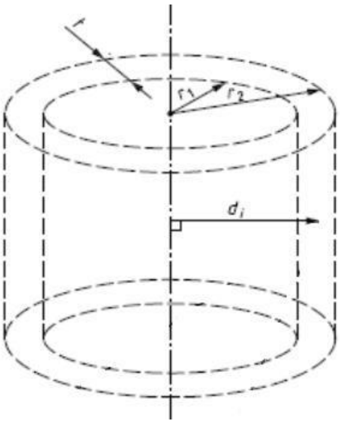

Figure 4. Cylindricity tolerance as a nominal integral element

Deviations in cylindricity may be classified based on their nature per STN EN ISO 12180-1: 2011 into:

- Centre line deviations.
- Radial deviations.
- Cross-sectional deviations.

Cylindricity measurement is always conducted on a CMM; it may also be performed on machinery designed for measuring shapes or cross-sectional measurements. The ideal and optimal method of checking for deviations in cylindricity is defined in STN EN ISO 12180-2: 2011, which describes filter properties, the shape of the sensor, the radius of the contact probe tip and the scanning force. Given the 3D nature of cylindricity as a characteristic, the development of a measurement strategy is particularly important. Given the fact that there was no technical documentation for the cylindricity tolerance for the specific component used in the experiment, a general tolerance of *t = 0.2 mm* was selected for the experiment itself [Dovica 2013].

3 LOGISTICS OF THE EXPERIMENT

A specific combination of the Taguchi methods of design and evaluation of experiments and MSA (measurement system analysis) tools were used to conduct and evaluate the experiment to determine fulfilment of the specified objective of the research itself. The experiment plan is depicted in Fig. 5.

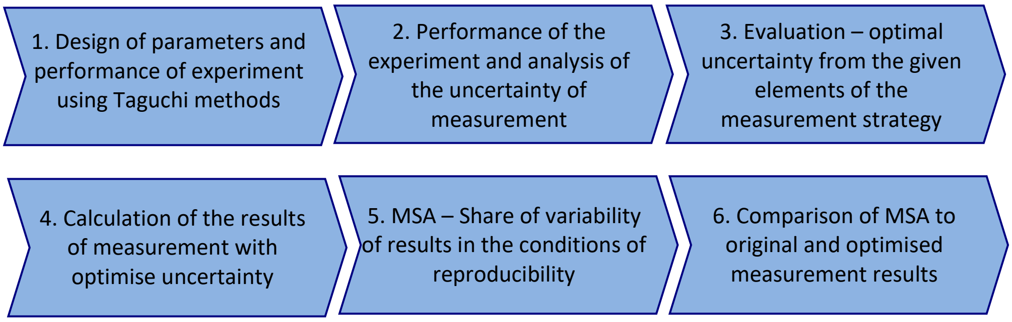

Figure 5. Logistical plan of the experiment

Calculation and graphical outputs were obtained using *Minitab 17* statistical software, which is specifically designed for quality assurance processes inside organisations. The systematic error of the employed CMM was intentionally left out of the results for transparency purposes because, as shown below, this error is two orders of magnitude smaller than the obtained results and therefore should not have any impact on the final values [Daneshjo 2017a], [Daneshjo 2017b].

4 PERFORMANCE OF THE EXPERIMENT USING TAGUCHI METHODS

The standard procedure was used in the application of the Taguchi methods on the investigated problem. The basic step in the first phase was to define the investigated process and specify the input variables in the experiment, i.e. factors, and elements of the measurement strategy in this case. This quantity was also influenced to comply with the MSA requirements for a minimum quantity of measurements for the subsequent processing of the obtained data.

After consultation with other scientists and experts in coordinate measurements in similar applications, the decision was made to involve 4 elements of the measurement strategy in the experiment with 3 levels defined for each individual element. Brainstorming was thereby eliminated, as the actual method dictated these phases of the experiment. Figure 6 depicts the P-diagram of the experiment.

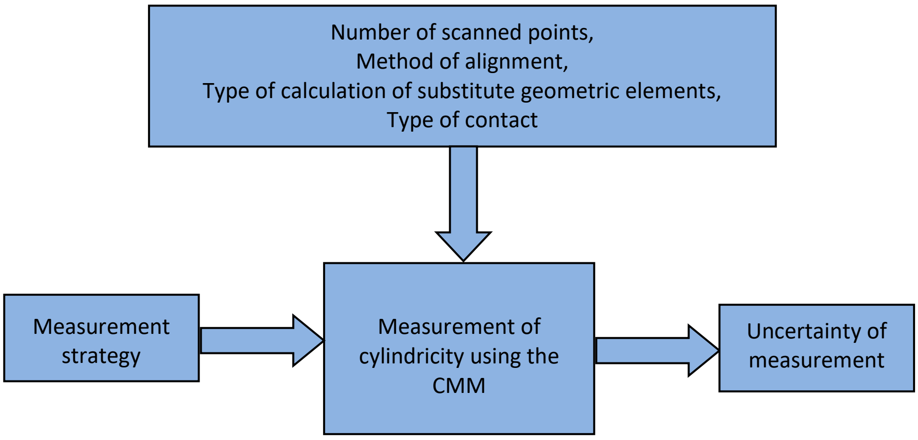

Figure 6. P-diagram of the experiment

The following input factors, i.e. elements of the logistical measurement strategy, were included in the experiment (Tab. 1):

- *Number of scanned points* – cylindrical tolerance was determined by measuring standard points distributed per the applicable standard while varying the overall number of these points.
- *Alignment method* – the 3-2-1 method was always used to align the coordinate system of the component with the CMM coordinate system, but three different combinations of surfaces used to define planes, lines and points were used.
- *Type of calculation of substitute geometric elements* – this calculation was performed sequentially by using three different algorithms.
- *Type of contact* – the scanning system used three different types of contact including changing the length of the shaft and, especially, the diameter of the ball used as the point of contact during the experiment.

A suitable type of orthogonal array was selected after defining these input variables for the experiment. The L^9 array was suitable for these needs as it works with nine rows as the number of repetitions completed with different combinations of the selected elements of the measurement strategy.

Selected elements of the measurement strategy				
Name	Number of scanned points	Method of alignment	Calculation of substitute geometric elements	Type of contact
Level 1	20	1	LSQ	2.40
Level 2	20	2	MIN_SEP	3.30
Level 3	20	3	IN_MIN	4.40

Table 1. Measurement strategy elements used in the experiment

This array (Tab. 2) also meets MSA-related requirements, which specify the evaluation of a minimum of three operators with three repeated measurements; repetitions 1 to 3 simulate operator A, repetitions 4 to 6 simulate operator B and repetitions 7 to 9 operator C. The selected orthogonal array is suitable for conducting the experiment according to the Taguchi methods and for simulating industrial conditions, Table 3.

L9 (3^4) Orthogonal array					
Experiment no.	Indepentdent Variables				
	Variable 1	Variable 2	Variable 3	Variable 4	Performance
1	1	1	1	1	P^1
2	1	2	2	2	P^2
3	1	3	3	3	P^3
4	2	1	3	3	P^4
5	2	2	1	1	P^5
6	2	3	2	2	P^6
7	3	1	2	2	P^7
8	3	2	3	3	P^8
9	3	3	1	1	P^9

Table 2. Orthogonal array used in the experiment

The determined uncertainty of measurement was the output in this experiment as it describes the variability of measurement results. The absolute values of these uncertainties were used in the calculation as the Taguchi methods only use positive values.

L9 (3^4) Orthogonal array				
Experiment no.	Independent variables			
	Number of scanned points	Method of alignment	Calculation of sub. geom. elements	Type of contact
1	20	1	LSQ	3,40
2	20	2	MIN-SEP	3,30
3	20	3	IN-MIN	4,40
4	30	1	MIN-SEP	4,40
5	30	2	IN-MIN	2,40
6	30	3	LSQ	3,30
7	40	1	IN-MIN	3,30
8	40	2	LSQ	4,40
9	40	3	MIN-SEP	2,40

Table 3. Orthogonal array propagated with the selected elements of the measurement strategy

4.1 SELECTING THE TRACK TO ELIMINATE OCCURRENCE OF POTENTIAL CONFLICTS

A "*Smaller is better*" type calculation was performed in the calculation section as the natural objective of any optimisation of measurement tool operation is to minimise the variability of results, and therefore minimise the uncertainty in the measurement results. The calculation results, through the offset/noise values, demonstrated the effects elements of the logistical measurement strategy used in the experiment have on an output characteristic, the uncertainty of measurement, in the form of their mutual ranking and the presentation of the relative effect between the individual levels of these elements and therefore the effect of a change in level of the individual elements. The results are presented in the form of the original output generated by the *Minitab 17* software.

Normal distribution of the measured data had to be checked before starting the calculations to meet the prerequisites for using a linear regression model and the MSA tool. Fig. 7 depicts the test for normal distribution of the data. Essentially, this process included an Anderson-Darling test and a hull hypothesis on the normality of the examined data.

The null hypothesis is not rejected if the *P-value* is greater than or equal to a level of significance of α=*0.05*. This situation occurred in this experiment and the measured values are normally distributed, as the illustration below shows the *P-value* reached the threshold value of *0.005.* Fig. 8 clearly indicates that the mean value of the set of measured values is *0.01807 mm*, which was then considered the nominal (theoretically correct) value of cylindricity in the used components in this experiment.

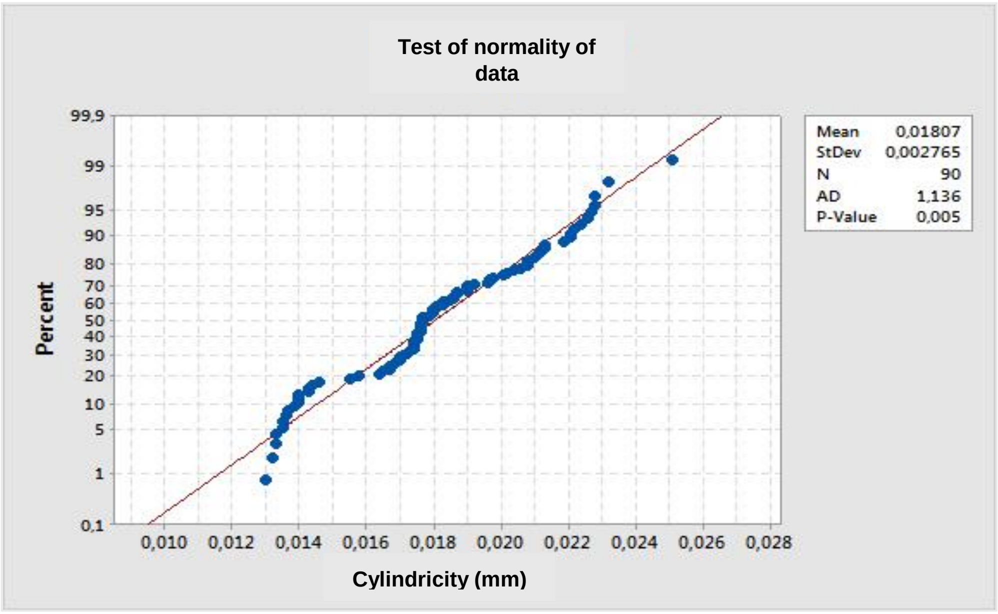

Figure 7. Test of normality of measured values

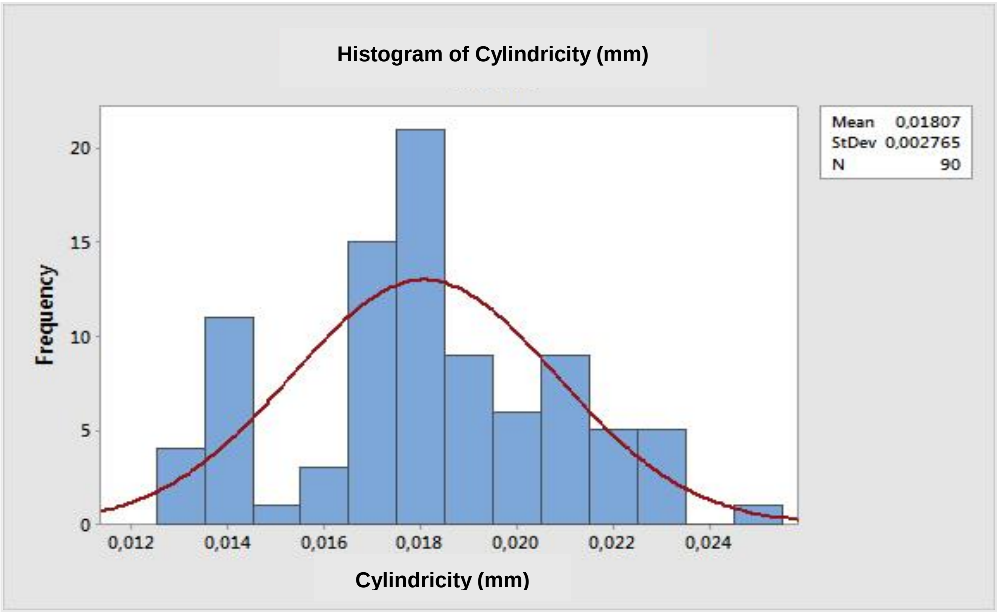

Figure 8. Histogram of measured values

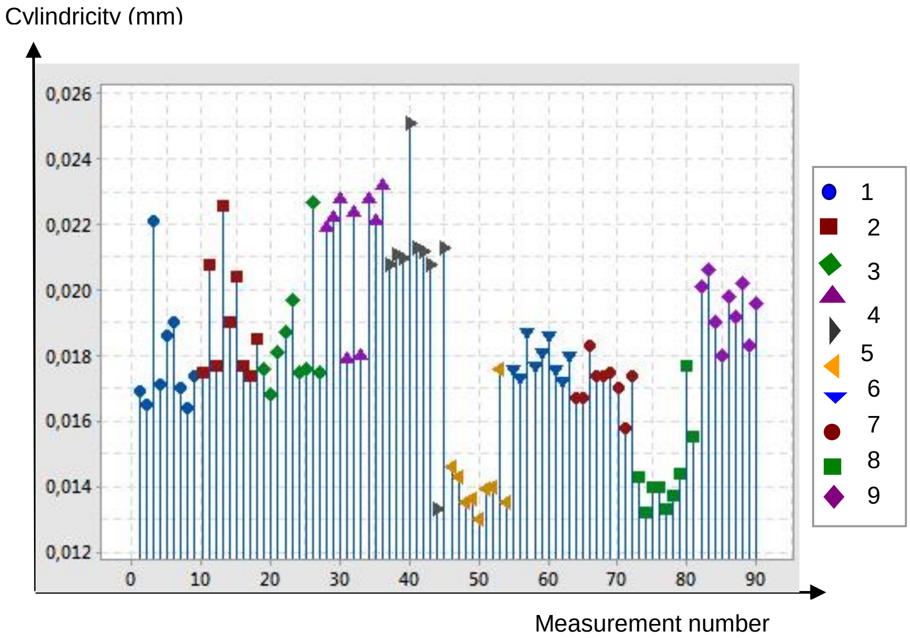

Figure 9. Measured values in graphical form

Taguchi Analysis: Uncertainty vs. Number of scans; Method of alignment; Calculation of repl.; Type of contact

Response Table for Signal to Noise Ratios
Smaller is better

Level	Number of scanned points	Method of alignment	Calculation of sub. geom. elements	Type of contact
1	59.37	59.40	60.10	62.17
2	57.53	57.02	56.72	59.68
3	57.98	58.47	58.06	53.04
Delta	1.84	2.38	3.38	9.13
Rank	4	3	2	1

The results of Taguchi analysis indicate that the selected type of contact had the greatest effect of the elements of the measurement strategy used in the experiment, followed by the type of calculation of substitute geometric elements, the method of alignment and the number of scanned points. For a better understanding, this calculation was repeated by quantifying the actual contribution of these elements to total uncertainty of measurement using the mean values of their effect.

Response Table for Means

Level	Number of scanned points	Method of alignment	Calculation of sub. geom. elements	Type of contact
1	0.000886	0.000915	0.000803	0.000649
2	0.001073	0.001380	0.001361	0.000845
3	0.001263	0.000926	0.001057	0.001728
Delta	0.000377	0.000465	0.000559	0.001079
Rank	4	3	2	1

To define an optimum combination of elements of the measurement strategy and to quantify the effects of this combination as the minimum possible contribution to uncertainty calculated based on measured data is possible by analysing the results in terms of the relative changes in signal offset/noise facilities.

Taguchi analysis: Predicted values for uncertainty:

Mean
0.0000315

Factor levels for predictions

Number of scanned points	Method of alignment	Calculation of substitute geometric elements	Type of contact
20	1	IN_MIN	2.4

The *Mean* value represents the best possible outcome in terms of uncertainty achieved in the conditions of the combinations of selected elements of the measurement strategy. Analysis of variance was the next step in completing analysis, together with determining the parameters of the regression model, the elements of which are defined by the selected orthogonal array.

General linear model:

Factor	Type	Levels	Values
Number of scanned points	Fixed	3	20; 30; 40
Alignment method	Fixed	3	1; 2; 3
Calc. of sub. geo. elements	Fixed	3	N_MIN; LSQ; MIN_SEP
Type of contact	Fixed	3	2.40; 3.30; 4.40

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Number of Scanned Points	2	0.000002	0.000001	0.91	0.407
Alignment method	2	0.000004	0.000002	1.80	0.171
Calc. of sub. geo. elements	2	0.000005	0.000002	2.00	0.142
Type of contact	2	0.000020	0.000010	8.45	0.000

Error	81	0.000095	0.000001
Total	89	0.000126	

Model Summary

S	R-sq	R-sq(adj)	R-sq(before)
0.0010830	24.53%	17.07%	6.82%

Regression Equation

Uncertainty = 0.001074 - 0.000188 Number of scanned points_20 -

- 0.000001 Number of scanned points_30 +

+ 0.000189 Number of scanned points_40 - 0.000159 Alignment method_1 +

+ 0.000307 Alignment method_2 - 0.000148 Alignment method_3 -

- 0.000271 Calc. of sub. geom. segments_IN_MIN

+ 0.000288 Calc. of sub. geom. segments_LSQ -

- 0.000017 Calc. of sub. geom. segments_MIN_SEP -

- 0.000425 Type of contact_2.40 - 0.000229 Type of contact_3.30 +

+ 0.000654 Type of contact_4.40

The results of analysis of variance and the linear regression model were used to complement the results determined through previous calculations. The *P-values* in the right-hand side of the analysis of variance results permit the determination of which of the elements of the measurement strategy had a statistically significant influence on the determined uncertainty of measurement. Type of contact, with a $p \leq 0.001$ was involved in this case, as its value is less than the standard level of significance of $\alpha = 0.05$ used in the standard statistical tests. Therefore, the null hypothesis that there is no relationship between type of contact and uncertainty of measurement may be dismissed. The analysis of variance also permits the precise definition of the percentage effect of the elements of the measurement strategy by expressing the share of the sum of squares of deviations pertaining to the individual elements and the total sum of squares of the variability of the examined data set. The following values are obtained:

1.Type of contact: 64.69%
2.Calculation of substitute geometric elements: 16.18%
3. Method of alignment: 12.92%
4. Number of points: 6.48%

The linear regression model provides additional important information via the coefficient of regression R^2, which shows what percentage of variability in the investigated data set (determined uncertainty) can be explained through this model and described in the form of an equation. The value in this case is *24.53%*, which gives an accurate idea of the distribution of the determined uncertainties by source, see Tab. 4.

Number of measurement	Component	Cylindricity (mm)	Uncertainty of measurement (mm)	Uncertainty unexplained by the model – 24.53% (mm)	Uncertainty unexplained by the model – 75.47% (mm)	Type of contact – 15.87% (64.69% of explained uncertainty) (mm)	Calculation – 3.97% (16.18% of explained uncertainty) (mm)	Method of alignment – 3.17% (12.92% of explained uncertaint) (mm)	Number of points – 1.59% (6.48% of explained uncertaint) (mm)
1	1	0,016900	-0,000989	0,000243	0,000746	0,000157	0,000039	0,000031	0,000016
2	1	0,016500	-0,001389	0,000341	0,001048	0,000220	0,000055	0,000044	0,000022
3	1	0,022100	-0,004211	0,001033	0,003178	0,000668	0,000167	0,000133	0,000067
4	1	0,017100	-0,000789	0,000194	0,000595	0,000125	0,000031	0,000025	0,000013
5	1	0,018600	-0,000711	0,000174	0,000537	0,000113	0,000028	0,000023	0,000011
6	1	0,019000	-0,001111	0,000273	0,000839	0,000176	0,000044	0,000035	0,000018
7	1	0,017000	-0,000889	0,000218	0,000671	0,000147	0,000035	0,000028	0,000014
8	1	0,016400	-0,001489	0,000365	0,001124	0,000236	0,000059	0,000047	0,000024
9	1	0,017400	0,00489	0,000120	0,000369	0,0000078	0,000019	0,000015	0,000008

Table 4. Component 1 and composition of uncertainty of measurement based on calculated data

A review of the completed activities, the applied procedures, tools and determined information:

1. Taguchi methods were used to complete an array design of the experiment, where four selected elements of the logistical measurement strategy were positioned on the input side and the observed characteristic of uncertainty of measurement in the cylindricity tolerances of dozens of components as the output. The arithmetic average of the measured indicators for the entire set of 90 measurements was used as the nominal value of cylindricity.
2. A test for normal distribution of the measured data was completed.
3. As per the Taguchi methods, the effect of selected elements of the logistical strategy on the uncertainty of measurement was evaluated by using deviations in the signal/noise, analysis of variance and the regression model and the optimal combination of elements that would theoretically provide the minimum amount of uncertainty,
4. The optimum amount of uncertainty was quantified and used to replace the originally determined uncertainty of measurement,
5. Using the MSA method of repeatability and reproducibility, the variability in the original set of measured values and the set with minimal uncertainty in the conditions of reproducibility were evaluated,

7. The determined minimal effect was verified by calculating the regression model of elements of the measurement strategy and the relative change in uncertainty between the individual repetitions
8. The calculations were complemented by MSA graphical tools.

6 CONCLUSIONS

Regarding the low level of maximum acceptable error in current coordinate measurement systems, nearly all of the results variabilities in measurement account to logistics and measurement strategy. A strategic approach to measurement, as a complex of interchangeable parts of a coordinate measuring machine, and methods for positioning components for measurement in the working area, obtaining scanning points and using commands in the control and evaluation software are completely in the hands of the operator. This creates rather significant room for many variations that could result in different measurement results for the same machine component.

This assertion underlines the fact that standard contemporary measurement protocols for using coordinate measuring machines as an official outcome of such measurements does not contain any information about the selected strategy. The primary objective of this experiment was to investigate the effect measurement strategy has on coordinate measuring machines in terms of the reproducibility of measurement results.

The results of such investigation may contribute to a better understanding of this continuously overlooked issue. Experimental conclusions can be applied in technical practice to ensure a high level of quality in measurement results on coordinate measuring machines. They may also serve as an inspiration for its distinct attitude to achieving resulting through an innovative combination of applied methods.

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REFERENCES

[Ali 2008] Ali, S. H. R. The influence of fitting algorithm and scanning speed on roundness error for 50 mm standard ring measurement using CMM. Giza: National Institute of Standards, 2008. 53 s.

[Bosch 1995] Bosch, J. A. Coordinate measurement machines and systems. New York, USA: Marcel Dekker Inc., 1995. 449 s. ISBN 0-8247-9581-4

[Daneshjo 2012] Daneshjo, N. Computers Modeling and Simulation. Advanced Materials Research Vols. 463-464 (2012) pp 1102-1105.Online available since 2012/Feb/10, ISSN- 1662-8985 Trans Tech Publications, Switzerland doi:10.4028

[Daneshjo 2017a] Daneshjo, N. and Danishjoo, E. General Course of Failure Distributions at Complex Machineries. In: TEM Journal. Volume 6, Issue 1, Pages 17-21, ISSN 2217-8309, DOI: 10.18421/TEM61-03, February 2017. Published by: UIKTEN - Association for Information Communication Technology Education and Science. Novi Pazar, Serbia.

[Daneshjo 2017b] Daneshjo, N.**,** Majernik, M., Kralik, M. and Danishjoo, E. Logistics motion assignments in robotized systems. In: MM (Modern Machinery) Science Journal, No. February (2017), Prague, Czech Republic. ISSN 1803-1269 DOI: 10.17973/MMSJ.2017_02_2016193

[Dovica 2006] Dovica, M., Katuch, P., Kovac, J. and Petrik, M. Metrology in mechanical engineering, TU, SjF Kosice - 2006. - 351 s. - ISBN 80-8073-407-0.

[Dovica 2013] Dovica, M., Busa, J., Palencar, R., Duri, S., Soos, L., Vrba, I., Kelemenova, T., Skovranek, T. Comparison of methods for analysis of deviations from roundness. In: Measurement Techniques. Vol. 56 , no. 9 (2013), p. 1021-1025. - ISSN 0543-1972

[Fabian 2014] Fabian, M., Izol, P., Draganovska, D. and Tomas, M. Influence of the CAM parameters and selection of end-mill cutter when assessing the resultant surface quality in 3D milling. In: Applied Mechanics and Materials. Vol. 474 (2014), p. 267-272. - ISSN 1660-9336

[Feng 2001] Feng, C. S. A review of current geometric tolerancing theories and inspection data analysis algorithms. Gaithersburg: National Institute of Standards and technology, 2001, 16 s. MD 20899-0001.

[Kral 2014] Kral, J. Jr. and Kral, J. Verification of a three axis milling machine accuracy in the process of complex shaped part production. In: Applied Mechanics and Materials : Novel Trends in Production Devices and Systems. Vol. 474 (2014), p. 261-266. - ISSN 1662-7482

[Kralik 2011] Kralik, M. and Budisky, R. Checking the quality of the geometric parameters of products using three-dimensional coordinate measuring machines. In New trends in quality management -Nove trendy v manazerstve kvality, 2011,

[Zakharov 2006] Zakharov, O. V. and Brzhozovskii, B. A. Accuracy of centering during measurement by roundness gauges. Izmer. Tekhn., (11), pp. 20-22. Measur. Techn., 49, No. 11,1094-1097 (2006)

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