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Gage Repeatability and Reproducibility Analysis of Coordinate Measurements of a Cutting Tool

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ABSTRACT

The article presents the results of research concerning the analysis of the possibility of the innovative application of the LineScan non-contact laser measuring probe controlled by the ACCURA II coordinate measuring machine in the field of measurements of a selected cutting tool. In the study, the angle of a round cutting insert was measured. The influence of the selected elements of a measurement strategy i.e., the scanning speed v, the resolution k, and the number of measurement paths w on the repeatability of measurements and the value of the insert's angle was determined. In both cases, the number of paths had the greatest impact. The best repeatability was obtained for the smallest distance between points (k = 0.1 mm) and the largest number of paths (w =10). For those measurement strategies, which differed in the scanning speed (1 and 3 mm/s), the detailed GR&R analyses were carried out by using the ANOVA and EMP methods. For strategies with the scanning speeds of 1 and 3 mm/s, the variance of the measuring system was 0.9% and 0.5% of the total variance, respectively. However, these differences in repeatability were not statistically significant. It has been shown that the selected methodologies of measurements and measurement data processing ensure good measurement repeatability of the selected geometrical feature of a cutting tool.

Keywords: measurement repeatability, non-contact measurements, coordinate measuring technique, cutting tool, MSA, GR&R.

INTRODUCTION

Machining is one of the most important and common manufacturing methods. To ensure the reliability of a production system, the machining industry tries, among others, to improve the quality of cutting tools. Regardless of the solutions applied for this purpose, the fundamental problem is the quality of the obtained results of research and analyses, which are carried out based on measurement data [1]. If the obtained data is not sufficiently reliable, the consequence may be wrong decisions, which in turn may lead to negative disturbances during a machining process, which translates into low quality of manufactured products. To reach the sources of problems, it would be necessary to obtain quantified information of a numerical nature, which would enable deciding on, among others, checking the suitability of a measuring system for assessing the condition of a cutting tool.

According to Cepova L. et al. [2] the correct evaluation of a manufacturing process and parts is performed based on relevant data and it is a technical necessity. The condition of a cutting tool and the change in its geometry during machining were usually estimated based on vibrations and acoustic emission testing [3, 4]. However, with the development of modern technologies, various measuring systems began to be used to monitor the condition of cutting tools [5]. The best solution would be to use an ideal measuring system, which is characterized by the absence of errors in relation to a measured product [6], but of course it is impossible to achieve. However, measuring systems, which include a coordinate measuring machine (CMM), characterized by very high measurement accuracy are used to minimize measurement errors [7]. In addition, the use of coordinate measuring machines shortens the time needed to improve both the structures of elements and techniques used for their production [8, 9].

Measurements conducted by using a CMM can be performed in two modes – contact and non-contact. Altinisik B. et al. [10] found that the choice of the type of a measuring system mainly depends on the accuracy of measurements, as well as on the complexity of the geometry of a tested object. In the case of measurements of a cutting tool, it is reasonable to use a non-contact measuring system. This is due to the complex geometry of a tool and, above all, the complicated shape of its working part. The example of a non-contact measuring system is a laser measuring probe cooperating with a coordinate measuring machine. This measuring instrument enables obtaining point clouds with high resolution and reducing scanning time compared to measurements conducted by using a contact probe. Therefore, a non-contact coordinate measurement has many advantages. However, it is still important to evaluate the capability of these measuring systems to measure a cutting tool.

The accuracy of a measuring system depends on several factors. It was noticed that a measurement strategy has a significant impact on the measurement results in the coordinate measuring technique e.g., due to the adopted scanning speed, number of measurement points, their distribution, and measurement data processing methods. This applies to measurements of both micro- [11] and macro-geometry [12, 13]. There are still few available research results aimed at determining the impact of an applied measurement strategy on the results of non-contact coordinate measurements, because optical probes controlled by CMMs have been used relatively recently. Moreover, there are not many investigation results focused on assessing the capability of the above-mentioned measuring systems for measurements of cutting tools. For this reason, the experimental studies were carried out, the results of which are presented in this article.

The following sections of this paper concern the selection of the GR&R (Gage Repeatability and Reproducibility) analysis methods and measurement strategies of a considered geometric characteristic of a cutting tool ensuring good measurement repeatability, analysis of the influence of selected parameters on the repeatability of measurements of a cutting insert's angle and the GR&R statistical analyses of a measuring system for adopted measurement strategies.

Determining the capability of a non-contact measuring system for coordinate measurements of the selected measurement characteristics of cutting tools is very important to improve the durability and efficiency of cutting tools and their regeneration. The repeatability and reproducibility analysis helps in assessing the accuracy of measuring systems. It is considered as one of the most effective and most frequently used methods of assessing the suitability of measuring systems for specific measurement tasks [14, 15]. The repeatability and reproducibility analysis is the effective way of controlling a measuring system in terms of its variability [16]. The importance of the GR&R analysis results from the fact that this analysis enables assessing the measuring instrument's capability and the identification of sources of variability in an investigated system [17, 18]. It also takes into account the interpretation of the variation in the results of measurements made by a measuring instrument (repeatability) and the fluctuations of the results of measurements made, for example, by the operator (reproducibility) [19, 20]. The most used and widely described methods of the GR&R analysis in the literature are [6, 21]:

- Average and Range method (A&R),
- Analysis of Variance (ANOVA),
- Evaluating the Measurement Process (EMP),
- VDA 5 (German *Verband der Automobilindustrie*).

A&R and ANOVA are the methods explained in detail in the MSA (Mesurement System Analysis) manual [22] developed by AIAG (Automotive Industry Action Group). The A&R method is an approach that provides an estimation of both the repeatability and reproducibility of a measuring system [23]. It enables studying the variability between measured parts and e.g., operators or applied measurement strategies. The variation due to the interaction between the operator and a part is not considered in this method. The A&R method is mainly used when statistical programs cannot be accessed. ANOVA, on the other hand, is used in most statistical programs. The MSA handbook [22] prefers this method because it can provide a more accurate estimation of variance and extracts the interaction between a part and, for example, the operator from experimental results. This technique is very useful, especially when many factors are tested at different levels [14].

Guidelines for evaluating the capability of a measuring system are specified in the MSA manual [22] and they are based on percentage components of variance for A&R and ANOVA. When analysing a measuring system, *GRR(%TV)* and *GRR(%tol)* are calculated by using these methods for the total variance and tolerance, respectively. A measuring system is rejected when the percentages of the above indicators exceed 30%. If the ratios are less than 10%, a measuring system is considered adequate. A system will be conditionally accepted when the *GRR* is greater than 10% and less than 30%. In the EMP method, developed by Wheeler [24], the assessment of a measuring system is made based on the *IC* (Intraclass Correlation) index. After calculating *IC*, an investigated system is classified into one of four classes. For each class, the value of the process signal attenuation is associated. In turn, the idea of the GR&R analysis according to the VDA 5 manual is based on the assessment of the measurement uncertainty [25].

Each of the above-mentioned GR&R analysis methods has its own application to assess the capability of measuring systems. In this work, two methods were chosen i.e., ANOVA and EMP. Based on the literature, it was noted that the analysis of variance is one of the most popular methods of the GR&R analysis, and the EMP method is an innovative approach to the evaluation of measuring systems. The choice of these methods was also made taking into account the fundamental purpose of the research i.e., to determine the capability of a non-contact measuring system based on a laser measuring probe cooperating with a CMM to measure a tool used in machining.

MATERIALS AND METHODS

The experimental research was divided into two main stages. The preliminary and final investigations were carried out, the purpose of which was to verify the applicability of the selected measuring system for coordinate measurements of a cutting tool.

Preliminary research

The purpose of the preliminary tests was to extract sets of measurement parameters of the selected geometrical characteristic of a cutting tool, for which the detailed GR&R analysis was carried out during the final investigations. The analysed measurement characteristic was the angle α of the side surface of the cutting insert (Fig. 1). The manufacturer of the considered cutting insert (R300-0828E-KL H13A) is the Sandvik company. The larger nominal diameter of the cutting insert is equal to 8 mm. The cutting insert is designed for machining e.g., nickel, and titanium alloys. The choice of the round cutting insert was associated with other research regarding the new way of leading a tool in five-axis milling [26, 27]. Different parts of a cutting edge are engaged at different machining stages so that an insert wears more evenly. This enables better use of the cutting potential of an insert.

Coordinate measurements of the mentioned characteristic of the cutting tool were carried out by using the ACCURA II coordinate measuring machine equipped with the LineScan 2-8 non-contact measuring probe by Carl Zeiss (Fig. 2). Based on the experience gained in operating the selected measuring probe and the results of the previous studies [28], it was established that experimental research should mainly focus on the analysis of repeatability of measurements. For this purpose, the experiment was developed, the idea of which is common to, among others, the Taguchi method aimed at minimizing the impact of disturbances [29, 30]. In this case, the noise was the repeatability of measurements. The key issue was to gain additional knowledge about the

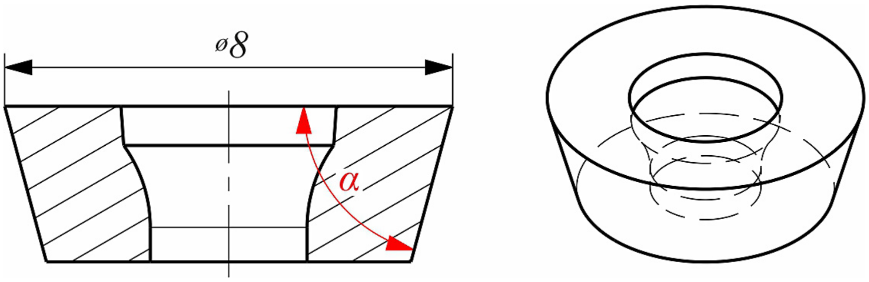

Fig. 1. The round insert with the marked analysed angle α

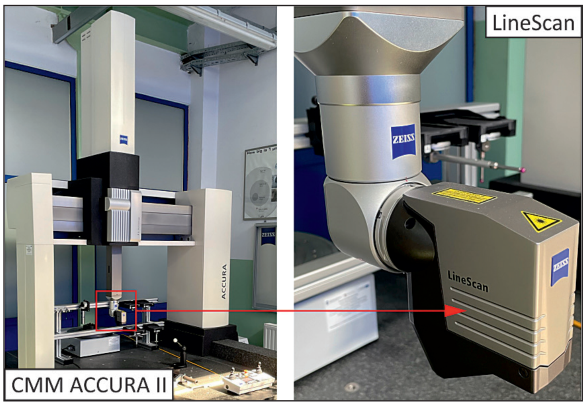

Fig. 2. The applied coordinate measuring system

measurement process. It was noticed that the main measurement parameters in the adopted measuring system that can be controlled by the user are:

- distance between points k, mm (measurement resolution),
- measurement speed v, mm/s,
- number of paths of the LineScan measuring probe w.

To obtain sufficient information regarding the impact of the above-mentioned parameters on the measurement results and to determine the repeatability of measurements, the test plan was used (Table 1), in which the resolution and the number of measurement paths had two levels, and the measurement speed, depending on the resolution, two or three levels of variability. In the case of the conducted tests, the measurement speed depended, among others, on the measurement resolution and the exposure time. The following resolution values were adopted in the preliminary tests: 0.1 mm and 0.5 mm. For k = 0.1 mm, the scanning speed v can be changed in the range of 1–3 mm/s. The extreme values of the speed were taken into account in the experiment plan. Additionally, in the case of tests for k = 0.5 mm, the speed close to the maximum speed i.e., 16 mm/s was taken into account. In order to test repeatability, each run was repeated four times.

The test results obtained in the form of measurement point clouds were imported into the Zeiss Reverse Engineering 2.8.0 (ZRE) software. On their basis, the conical surface was fitted by using the best fit method with the fit tolerance of 0.01 mm (Fig. 3). In this way, the value of the angle of the side surface of the round cutting insert was determined. It was noticed that the results obtained in the measurement series are very different. The measurement series was understood as the data obtained by repeating the measurements four times while maintaining the same measurement parameters. In ZRE, it was checked what impact the boundary points have on the obtained measurement results of the insert's angle. Even at the stage of coordinate measurements, the Calypso software controlling the operation of the CMM ACCURA II indicated that boundary points may be of low quality. It was found that after removing the boundary points in all scans (Fig. 3c), the results in each measurement series are more similar than before editing the point clouds. Thus, the angle of the side surface of the cutting insert was calculated after generating the conical surfaces based on the point clouds without taking into account the boundary points (Fig. 3d).

The parameter of the variability of the results of repeated non-contact coordinate measurements was the logarithm of the standard deviation of the angle. The variance of the standard deviation is proportional to the mean value. This is inconsistent with the assumptions of the analysis of variance that was to be used. This problem is eliminated by taking the logarithm of the standard deviation, as in the analysis of the Taguchi experiment. However, unlike the Taguchi method, the signal-to-noise ratio (SNR) was not used in the analysis of the results not to make repeatability dependent on the mean value. The statistical analyses were performed by using the JMP 12 statistical software. The significance level was equal to 0.05 during all conducted investigations.

Due to the main purpose of the research i.e., to determine the capability of the non-contact measuring probe to measure the cutting tool, it was of primary importance to determine the parameters that ensure good repeatability of measurements. There are still few outcomes of investigations aimed at determining the impact

Table 1. The experimental plan for the preliminary research

Run / parameters	1	2	3	4	5	6	7	8	9	10
k, mm	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.5	0.5
v, mm/s	1	1	3	3	1	1	3	3	16	16
w	3	10	3	10	3	10	3	10	3	10

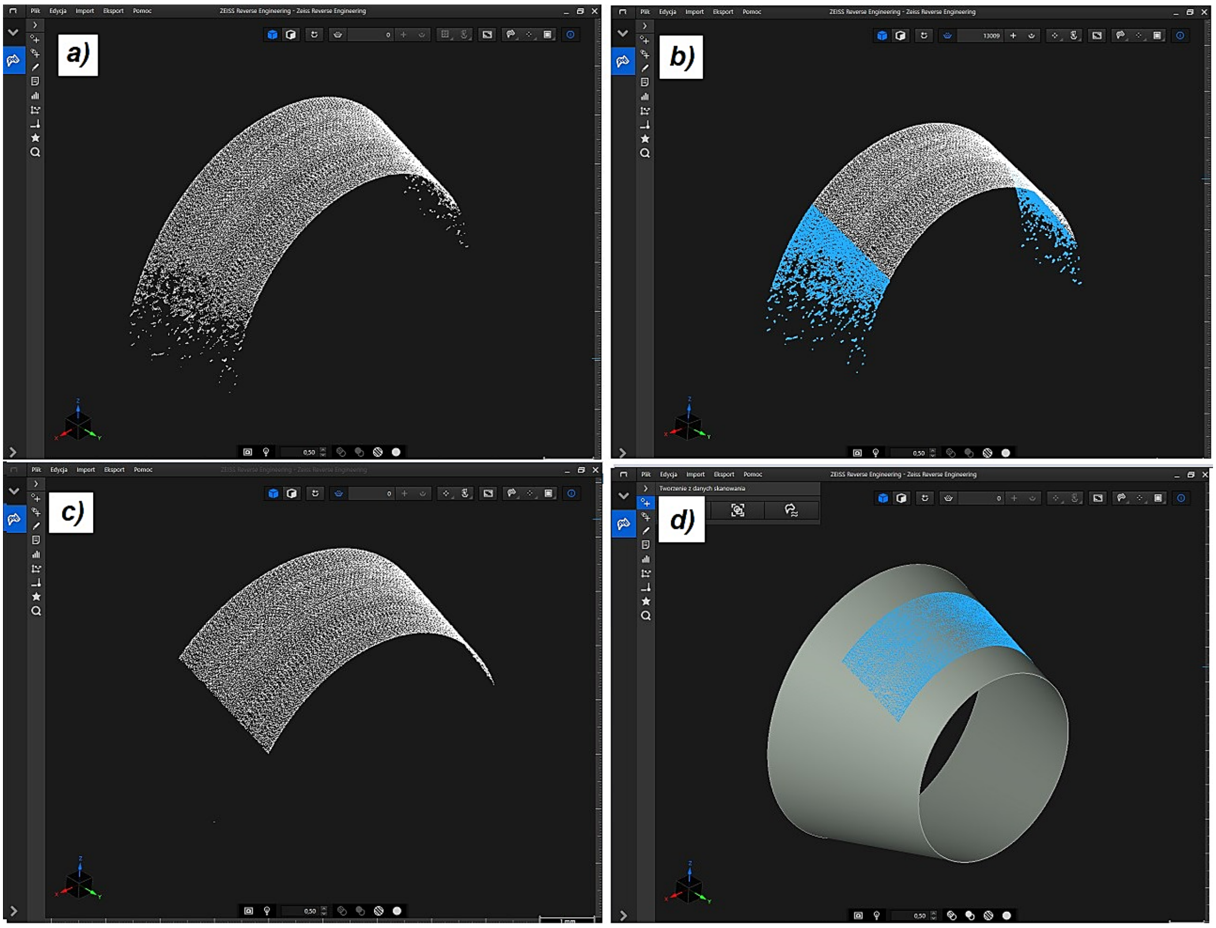

Fig. 3. Data processing in ZRE: (a) imported measurement data, (b) boundary points to be removed, (c) point cloud after removing the boundary points, (d) fitted conical surface

of measurement strategies on the results obtained by using non-contact coordinate measuring systems. For this reason, the coordinate measurements carried out during the preliminary tests concerned, apart from the analysis of the repeatability of the insert's angle measurements and the selection of measurement strategies for the final tests, the impact of the selected measurement parameters on the average value of the angle.

Final research

Based on the preliminary research concerning the analysis of the repeatability of coordinate measurements, sets of the measurement parameters were selected, which are presented in Table 2. These parameters were the basis for detailed repeatability studies based on the selected GR&R analysis methods of the measuring system: ANOVA and EMP. The investigations were carried out for two measurement strategies in which the variable was the scanning speed v. The following values of the measurement speed of the LineScan laser probe were used: v = 1 mm/s and v = 3 mm/s. The constant parameters were the resolution k = 0.1 mm and the number of measurement paths w = 10. Six new round cutting inserts were selected, and then their measurements were carried out, which were repeated five times. The values of the angles α of the selected cutting tools were determined in the ZRE software according to the previously described procedure, similarly to the preliminary tests. The nominal value of the considered angle of the cutting tool was 75°. In turn, the tolerance of the selected measurement characteristic was equal to ±15'.

Table 2. The experimental plan for the final studies

Run / parameters	1	2
k, mm	0.1	0.1
v, mm/s	1	3
w	10	10

RESULTS

Preliminary research

Influence of the measurement parameters on the insert's angle measurement repeatability

Based on the developed experimental plan (Table 1), the values of the angles α of the side surfaces of the cutting inserts were obtained (Fig. 4). The data presented in Figure 4 were the basis for further analyses as part of the preliminary research. The presented data indicate the very large dispersion of the results of the non-contact coordinate measurements. The reasons for this spread include measurement strategies used during the measurements, taking into account the various combinations of the values of the k, v and w parameters. Therefore, the special attention should be paid to the need to carefully select the measurement parameters that are the basis of the individual strategies to obtain accurate (showing the smallest dispersion) results of coordinate measurements of the selected characteristic of the cutting tool. The influence of the measurement parameters i.e., the distance between points k, the scanning speed v and the number of paths w on the logarithm of the standard deviation of the insert's angle ($log(std.\alpha)$) was investigated by the analysis of variance. The results of the analysis are presented in Table 3 and Figure 5. The confidence interval of 0.95 was used.

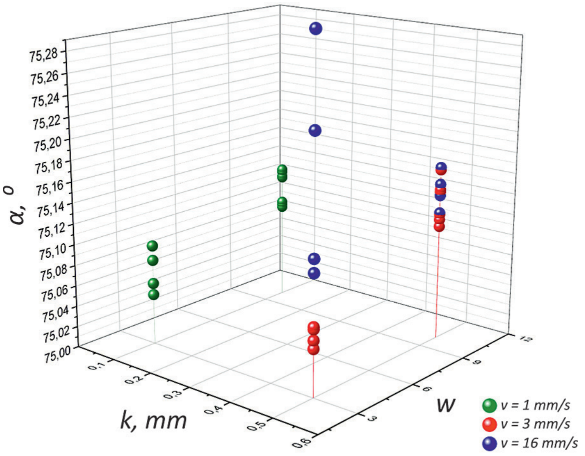

Fig. 4. The insert's angle α values calculated by using ZRE software

Among the analysed factors, only the number of measurement paths w turned out to have the statistically significant effect on the value of $log(std.\alpha)$. Therefore, it is worth paying attention to this parameter when developing a measurement strategy. Better repeatability (i.e., lower $log(std.\alpha)$) was achieved by using the higher value of w (more passes of the LineScan scanning probe along an investigated object). However, it should be taken into account that the conducted analysis did not include the interaction effects and showed the averaged influence of the tested parameters on the measurement repeatability.

In order to determine the set of the values of the measurement parameters (creating measurement strategies) by using which the best repeatability of coordinate measurements was obtained, the measurement results were presented in the graphical form (Fig. 6). Three groups of data can be observed in Figure 6. For this reason, the chart was divided into three conventional parts representing respectively:

- the worst repeatability of the selected measuring system ($log(std.\alpha) > -3$), obtained for the highest scanning speed v and the smallest number of measurement paths w,

Table 3. The results of the analysis of variance for the output variable $log(std.\alpha)$

Effect	DF	SS	F	p
k	1	0.523977	1.1242	0.3375
v	2	2.1502788	2.3096	0.1948
w	1	3.3237042	7.1401	0.0442

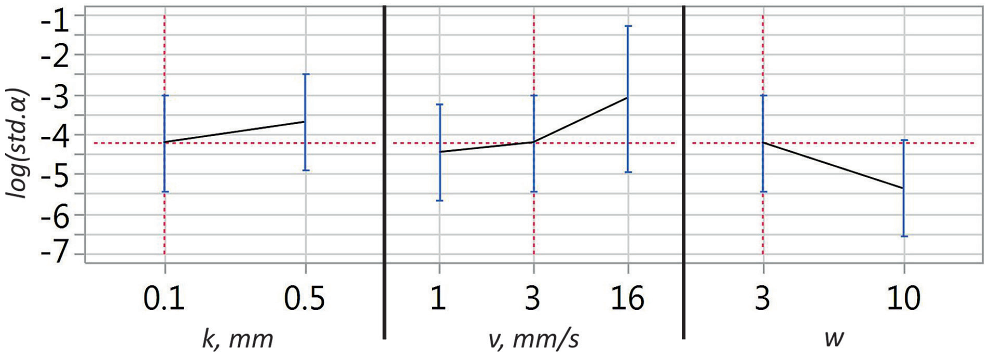

Fig. 5. The average influence of the measurement parameters on $log(std.\alpha)$

Table 4. The regression equation coefficients

Effect	Coefficient	Standard error	t	p	Standardized coefficient
Intercept	75.020524	0.006894	10882	<0.0001	0
k	0.0037919	0.01365	0.28	0.7828	0.019343
w	0.0093551	0.000723	12.93	<0.0001	0.848647
(*k*-0.3359)·(*w*-6.58974)	0.0100896	0.003675	2.75	0.0096	0.180077
log(*v*)	0.0105126	0.002723	3.86	0.0005	0.269206

- average repeatability ($-5.25 > log(std.\alpha) > -3$),
- the best repeatability ($log(std.\alpha) < -5.25$), obtained for the smallest distance between measurement points k and the greatest number of paths w. Moreover, for the measurement speed $v = 1$ mm/s better repeatability was obtained than for the measurement speed $v = 3$ mm/s.

Based on the analysis of the results of the preliminary tests, two measurement strategies were selected for the final investigations. The measurements of the insert's angle α were characterised by the best repeatability in the case of using the selected strategies. The selected measurement strategies were characterised by the following values of the resolution k, the scanning speed v and the number of paths w:

$k = 0.1$ mm, $w = 10$, $v = 1$ mm/s;
$k = 0.1$ mm, $w = 10$, $v = 3$ mm/s.

Influence of the measurement parameters on the average value of the insert's angle

In order to determine the influence of the measurement parameters on the average value of the insert's angle α, the additive mathematical model was determined, taking into account the main effects as well as two-factor and three-factor interactions. To improve the rotatability of the plan, the variable v was logarithmized. As a result of backward regression, the model was obtained, the parameters of which are presented in Table 4. The model was well fitted to the empirical data ($R^2 = 0.85$). The average values of the insert's angle α_avg obtained in the tests carried out are shown in Figure 7.

When analysing the values of the coefficients of the determined model for standardized data, the number of measurement paths had the greatest impact on the value of the insert's angle. The larger values of the insert's angle α were obtained for the larger value of the w parameter (Fig. 7). The effect of the scanning speed was also statistically significant. The higher scanning speed was associated with the higher value of the insert's angle. The effect of the resolution k was not statistically significant. However, the interaction between the distances between the points k and the number of paths w was important. Therefore, it is worth considering these parameters in the research and creating measurement strategies based on them for non-contact measurements.

Final research

Analysis of outliers and equality of variances

Figure 8 shows the angle values obtained by using the measurement strategies chosen

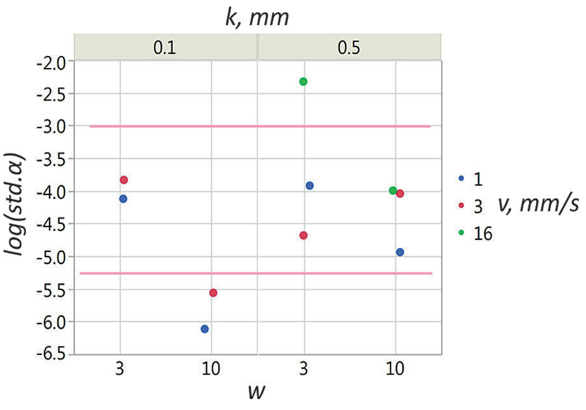

Fig. 6. The *log*(*std.α*) values for measurements made with the different measurement strategies

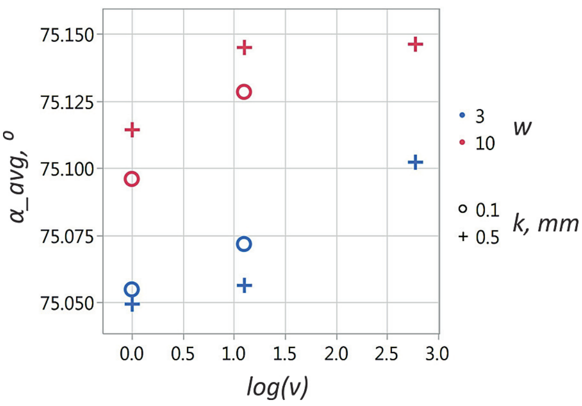

Fig. 7. The average values of the insert's angle depending on the measurement parameters

based on the results of preliminary tests. These strategies are presented in detail in the previous parts of this paper. These values were the basis for analysing the assessment of the capabilities of the selected coordinate measuring system, based on the CMM ACCURA II and the LineScan measuring probe, for measuring the cutting tool.

It is noticeable that for the scanning speed *v* = 1 mm/s, the repeatability of the results for the parts no. 3 and 5, expressed by their dispersion, is clearly lower compared to other measured cutting inserts. This is also confirmed by the data presented in Figure 9. The value of the dispersion for *v* = 1 mm/s and part no. 5 exceeds the control limit. After removing the smallest observed value of the angle *α* from the data set, all points presented in Figure 9 would be within the control limits. However, the analysis of the standardized residuals (*StdRes*), determined as a result of the analysis of variance, did not show the presence of outliers (the highest absolute value of *StdRes* was 1.96).

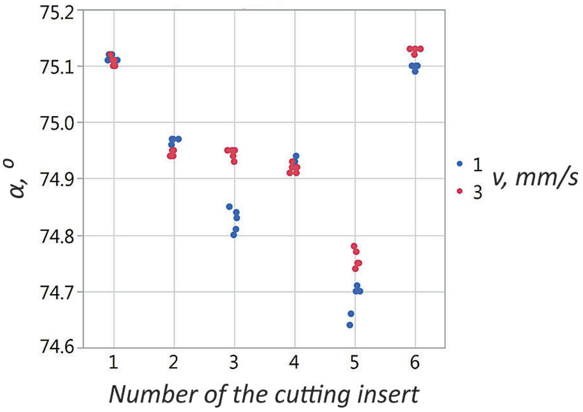

Fig. 8. The values of the angles *α* depending on the part and the scanning speed *v* for six cutting inserts

In order to check whether the inequality of variance had a significant impact on the results of the analysis of variance, the heterogeneity of variance test based on the Analysis of Means for Variances (ANOMV) was performed [31]. The test results (Fig. 10) did not indicate any significant differences in variance in individual groups. Therefore, it was not considered necessary to exclude any observation. The intersection of the graphs in Figure 11 indicates the presence of interactions between the measurement strategies and parts. However, this interaction was not the subject of the research. For each adopted strategy, the separate investigations of the measurement system's capability were performed by using selected GR&R methods i.e., ANOVA and EMP.

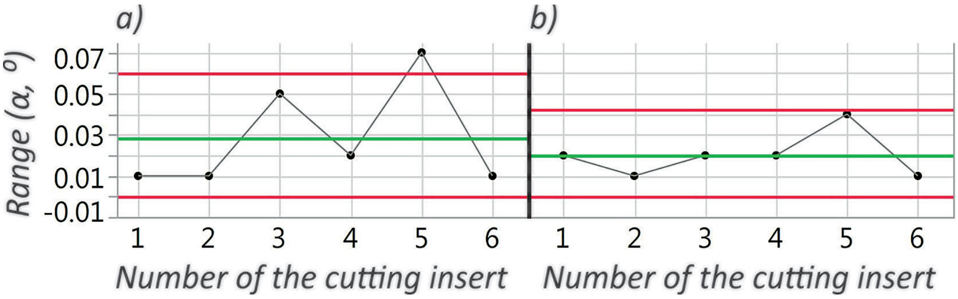

Fig. 9. The range charts including all observations: a) *v* = 1, mm/s, b) *v* = 3, mm/s

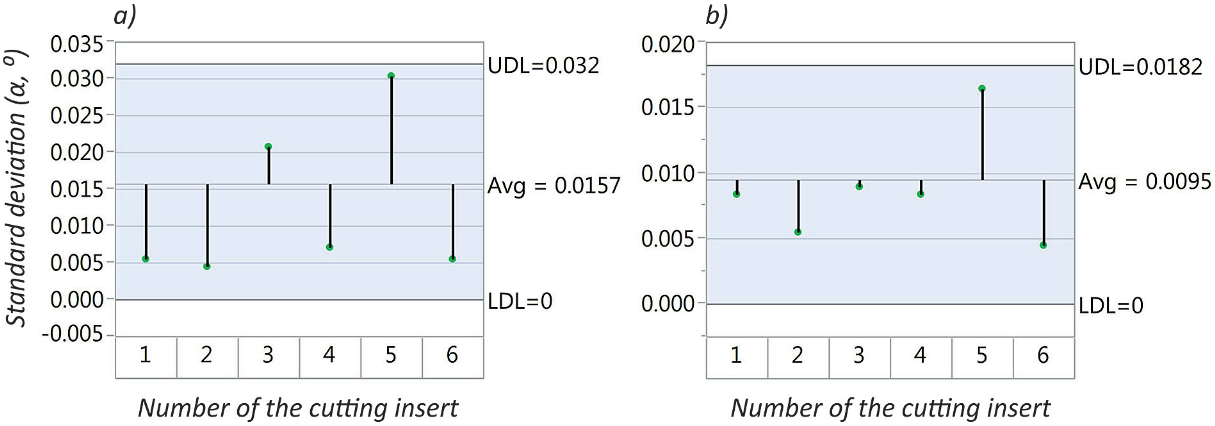

Fig. 10. The variance heterogeneity test results: a) *v* = 1, mm/s, b) *v* = 3, mm/s

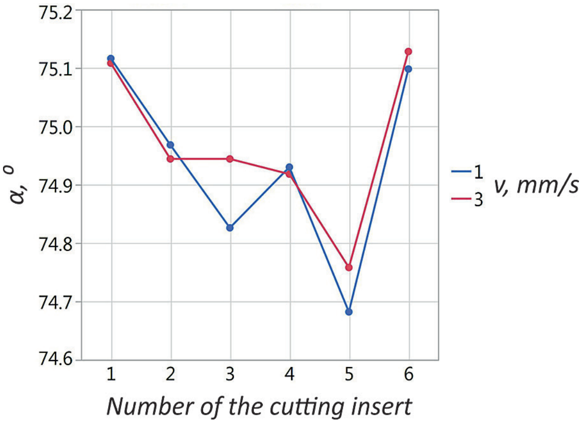

Fig. 11. The average values of the angles α for the cutting inserts depending on the measurement strategy

The GR&R analysis of the selected measuring system for the various measurement strategies

The distribution of the points on the average charts for the analysed data set (Figs. 12-13) is favourable. For both analysed measurement strategies, the points are largely outside the control limits, which proves that the measuring system can reveal differences between the measured parts.

The variance components for the analysed strategies are presented in Table 5. The results of the GR&R analyses are presented in Table 6. The GR&R indicators calculated by using the EMP method have lower values than in the ANOVA method. In the EMP method the components of variance from the measurement tool *GRR(%TV)* and the part *PV(%TV)* add up to 100%. This is not the case with ANOVA. Based on the ANOVA method and the AIAG classification [22], the measuring system, regardless of the adopted measurement strategy, is acceptable in terms of *GRR(%TV)* and conditionally acceptable in terms of *GRR(%tol)*. In the EMP method, the assessment of the measuring system is made on the basis of the *IC* index. In the conducted tests, *IC* was 0.9911 (v = 1 mm/s) and 0.9952 (v = 3 mm/s). In the case of $IC > 0.8$, the measuring system belongs to the first (highest) class. Systems in this class have process signal attenuation of less than 11%.

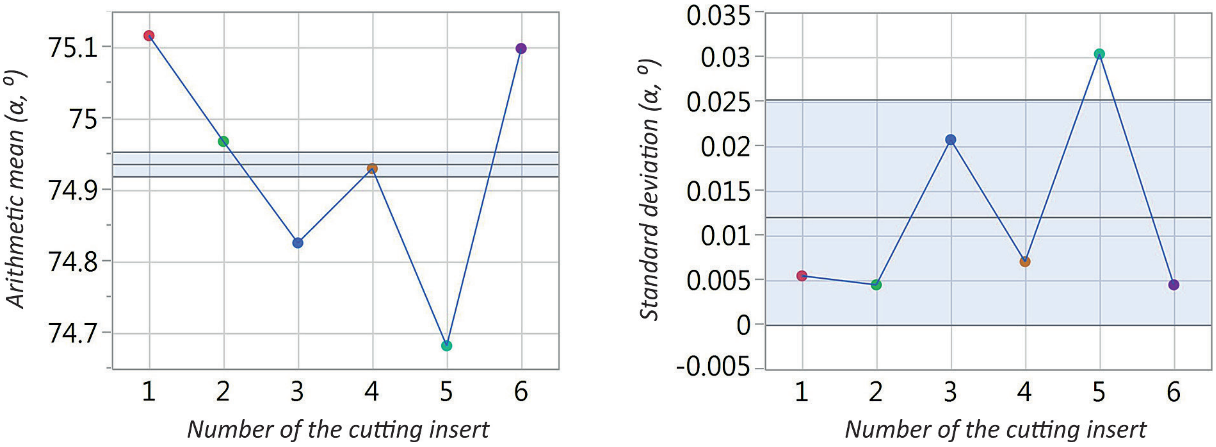

Fig. 12. The average and standard deviation charts – the EMP analysis for v = 1, mm/s

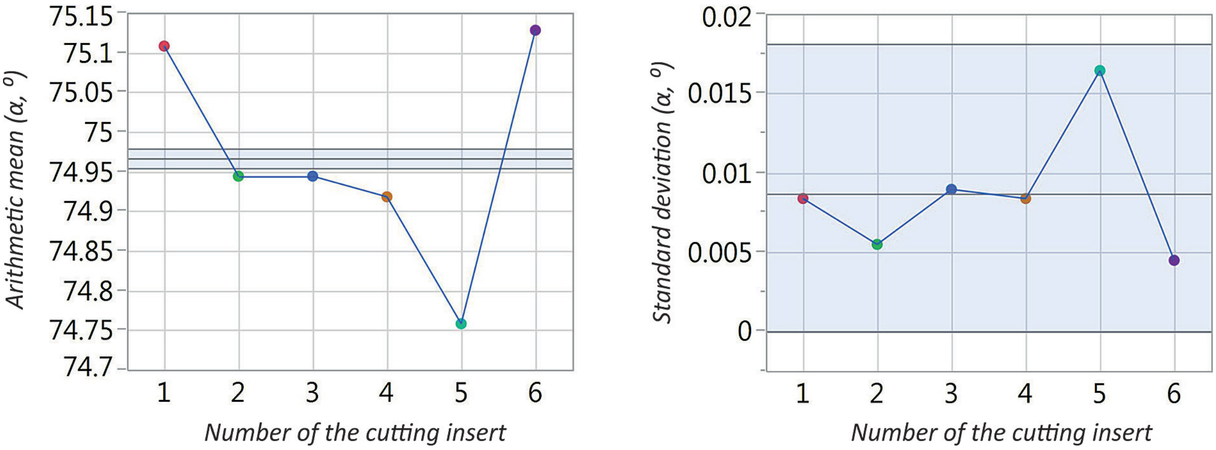

Fig. 13. The average and standard deviation charts – the EMP analysis for v = 3, mm/s

Table 5. The variance components

Component	*v* = 1 mm/s			*v* = 3 mm/s		
	Standard deviation	Variance	% of total variance	Standard deviation	Variance	% of total variance
Cutting insert	0.16458	0.02708573	99.11	0.13627	0.01857027	99.52
Within	0.01571	0.00024667	0.89	0.00949	0.00009000	0.48
Total	0.16533	0.02733240	100.0	0.13660	0.01866027	100.0

Table 6. The results of the GR&R analyses

Indicator	ANOVA		EMP	
	v = 1 mm/s	*v* = 3 mm/s	*v* = 1 mm/s	*v* = 3 mm/s
GRR(%TV)	9.5	6.94	0.89	0.48
PV(%TV)	99.54	99.76	99.11	99.52
GRR(%tol)	18.85	11.38	-	-
PV(%tol)	197.49	163.53	-	-
TV(%tol)	198.39	163.92	-	-

Comparing the analysed measurement strategies, better repeatability was obtained by using the scanning speed v = 3 mm/s. However, when analysing the logarithm values of the standard deviation of the results of repeated measurements of the angle $log(std.\alpha)$ for the given part (the cutting insert), no statistically significant differences were found between the measurement results obtained for different scanning speeds.

CONCLUSIONS

Measuring systems play a key role in supervising the production process and assessing its reliability. Measurements of cutting tools by using an optical probe integrated with a CMM are relatively poorly recognized. In the conducted research, attention was focused on the selected geometrical characteristic of the round cutting insert, which is the insert's angle of its side surface. The work was divided into two fundamental stages. In the first one, the influence of the scanning speed, the measurement resolution, and the number of measurement paths on the values of the insert's angle and the repeatability of measurements were determined. The conclusions from this stage of the research are as follows:

- the number of measurement paths w had the greatest impact on the value of the insert's angle α – the larger values of the angle α were obtained for the larger value of the parameter w,
- the scanning speed also turned out to be statistically significant – the higher values of the insert's angle α were obtained for the higher scanning speed v,
- the effect of the resolution was not statistically significant. However, the interaction of the resolution and the number of paths was important.

In the second stage of the experimental research, two measurement strategies were used (selected based on the results of the preliminary tests), for which the measurements were characterized by the highest repeatability. The GR&R analyses of the measuring system for the above measurement strategies were carried out by using the ANOVA and EMP methods. On their basis, the following conclusions were drawn:

- the repeatability of the measuring system in relation to the total variance turned out to be satisfactory for both measurement strategies regardless of the GR&R research methodology,
- based on the dimensional tolerance factor ($GRR(\%tol)$) the system would be considered conditionally capable. The obtained value of $GRR(\%tol)$ of 11.4% for the measuring speed v = 3 mm/s proves that the criterion of the accepted system is closer than the unaccepted system criterion,
- the variance of the measuring system was approximately 0.9% of the total variation for the strategy with v = 1 mm/s and 0.5% of the total variation for the strategy with v = 3 mm/s. However, no statistically significant differences were found between the $log(std.\alpha)$ values obtained for different scanning speeds when analysing the repeatability expressed by $log(std.\alpha)$ calculated for a given cutting insert.

The analysis of the capabilities of the measuring system consisting of the LineScan non-contact measuring probe cooperating with the ACCURA II coordinate measuring machine showed that the selected measurement and data processing methodologies ensure good repeatability during the measurements of the examined feature of the cutting tool i.e., the angle of the round cutting insert. It should be noted that the value of the angle depends not only on the measurement parameters, but also on the methodology of data processing performed by using the Zeiss Reverse Engineering software. This methodology was based on the removal of the group of boundary points in the point cloud and turned out to be effective when calculating the value of the angle of the side surface of the cutting insert.

The developed methodology of measurement data analysis can be used in industry for various contact and non-contact coordinate measuring systems. The applied parametric programming of a coordinate measuring system enables experimental research based on multiple coordinate measurements carried out for various measurement strategies and the implementation of mathematical models. Moreover, in the case of the CMM ACCURA II and the LineScan measuring probe, the user can apply the measurement strategy selected based on the results of the investigations to improve the accuracy of measurements of a cutting insert.

The purpose of further research will be to determine the capability of the non-contact measuring probe to investigate cutting edges of inserts and working parts of monolithic cutting tools. The obtained results will be the basis for research on the regeneration of cutting tools.

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