Zpět

Determination of the optical 3D scanner capability of measuring a geometric characteristic

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The measurement system analysis is a part of the quality assurance. In this field, the measuring device capability evaluation has an importance. Optical 3D scanner, as a non-contact device, is used for digitization and measuring. Aim of this paper is point to the possibility of measuring a small object, namely hard metal rod, using optical scanner. The issue was the evaluation of measuring capability of the GOM ATOS Triple Scan II optical 3D scanner when measuring the geometric characteristic of runout with using of various measuring volumes. Measuring of a small object is often difficult due to ensuring the measuring repeatability (precision) and high accuracy. Statistical method of repeatability of measurements was used for capability evaluation and for its expression in the form of capability indices. Based on the results it was able to confirm or refute the capability of this scanner to provide relevant data during measuring a small object.

Key words: Measuring, capability, repeatability, accuracy, 3D scanner

1 Introduction

Measuring systems based on non-contact principle are increasingly used in engineering metrology due to their effectiveness when measuring a objects, that is impossible to measure using coordinate measuring machines or could be measured very complicated. There are applications where is more useful to use non-contact method, optical non-contact measuring systems, for instance, instead of contact methods. Optical measuring systems exhibit effectiveness during measuring a small objects. As an example, the using of active triangulation scanning technique for shape investigation of worn cutting inserts was published by Morovič [1], effective measurement of wear process of milling tool based on optical method, published by Vopát [2] and Zhang [3], dimensional analysis of cutting inserts using optical multisensory device, published by Guniš [4]. Another research have been made, for instance, in the field of 3D reconstruction of small objects from a sequence of multi-focused images, as showed by Gallo [5], or an example of application of optical scanning in the Reverse Engineering process with additive manufacturing – Rapid Prototyping, as showed by Paulic [6].

However, whether such optical system is capable to provide relevant data is the issue. Measurement with optical system requires a specific approach of the operator. Such devices can operate in automatic mode of measuring, which ensures repeatability of data obtaining. As mentioned in [4, 7, 8], the standard defines repeatability as a closeness conformity between the results of measurements which were performed on the same object, carried out under the same conditions, like the same measurement procedure, using the same measuring equipment, measurement with the same operator, the same measurement place and conditions of environment during measuring and short time intervals between measurements. Repeatability is possible to evaluate and quantify by the characteristic of the precision of the results. Precision is the closeness of agreement between independent results, which were obtained under the specified conditions, i.e. under the conditions of repeatability. Thus, the repeatability of results relates to the precision of the measured values around the average value. It may be expressed, for instance, by standard deviation. In practical engineering, the Measurement System Analysis (MSA) handbook is used to complex measurement system analysis. MSA manual [8] and Minitab [9] describe a type 1 gage study that assesses the variation that comes only from the measuring device (gage). It assesses the effects of bias and repeatability on measurements from one measuring device and one reference part. This study takes into account only the gage, not any other sources of variation. Two indices are used for assessment a measuring device capability, C_g and C_{gk}. This method uses C_g index to evaluate the repeatability (random error of the measurement system) and C_{gk} index to evaluate the bias (systematic error of measurement system). Capability indices compare the width of tolerance field with bandwidth variability of the measured values. Index C_g takes into account only repeatability (precision) of measurements, it means that it characterize only the possibilities of process given by variability. Index C_{gk} takes into account also bias (accuracy), it means that it characterize the process variability and central location of values in tolerance field, which characterize the real capability of measuring device. If both of indices – C_g and smaller one from C_{gkU} or C_{gkL}, exceed the determined value 1.33, the measuring system is regarded as capable. Another type 2 study (R&R) deals with a total dispersion of measurement results from a one-to-one effect of repeatability and reproducibility [8, 10]. It analyzes variance not only from a measuring device (gage), but also from operators, method, etc. Evaluation of measuring process capability represents a share of measurement system variability, expressed as a percentage of tolerance class, in the total variance, as described by Mahovic [10]. Pearn [11] point to gauge measurement errors impacting the manufacturing capability estimating using empirical estimator. Analysis with usage of R&R study and ANOVA method in according to measuring process capability is referred by Al-Refaie [12]. An overview of theory and practice on process capability indices for quality assurance is widely described by Wu [13].

2 Proposal of the experimental work

The aim of experimental work was the evaluation of measuring device capability, namely GOM ATOS Triple Scan II optical 3D scanner. To achieve this goal, obtaining the sufficient number of relevant values for evaluation of capability was necessary. Statistical values obtained by experiment shall be considered as a quality characteristic. During measuring the sample – the hard metal rod, was necessary to keep required measurement settings and requirements determined by method of repeatability of measurements, as described in [7, 8].

2.1 Measurement conditions

The method of repeatability of measurements provides a clear measurement conditions which have to be complied to achieve credible measurements assessment. Measurement conditions were proposed before starting the measurements and they were constant for each one. Measurements were performed by one operator during short time intervals in appropriate laboratory environment conditions with air temperature 21 °C and humidity 56 %. Measurements were carried out at the same place, at the same position and in a short period of time.

2.2 Configuration of scanner, preparations and scanned object

Measurements were carried out by GOM ATOS Triple Scan II optical 3D scanner with installed chosen measuring volumes. Scanner has SO (Small Objects) configuration with one projector and two cameras. Whole optical system had to be warmed up to be in operating condition. Warming up took approximately 15 minutes. Parameters of ATOS scanner are in the Tab. 1.

Tab. 1 Parameters of ATOS scanner [14]
Tab. 1 Parametre skeneru ATOS [14]

Camera resolution	**Measuring volume MV100 (LxWxH)** [mm]	**Measuring volume MV170 (LxWxH)** [mm]	**Measuring point distance MV 100** [mm]	**Measuring point distance MV 170** [mm]	**Angle between cameras** [°]	**Measuring distance** [mm]
5 megapixels (2448 x 2050 pixels)	100 x 75 x 70	170 x 130 x 130	0.045	0.071	28	490

Calibration of optical system with help of calibration object clamped on rotary table was the next step. Calibration ensured the dimensional consistency of the measuring system. It was performed in terms of recommended procedure from manufacturer - GOM GmbH, as in [14, 15]. It consisted of recording the images in various distance, position and orientation of each camera in relation to calibration object clamped on rotary table. As a result, the characteristics of the camera lenses and chips were determined. Based on these data, software calculated 3D coordinates from the points of calibration object in the 2D camera. At the end of calibration process were shown calibration results for camera and projector.

For selected measuring volumes were recommended reference points with diameter Ø0.8 mm which were stuck on clamping system of scanned object. These points allow tracking of scanned object in the measuring space of scanner, correct orientation of this object and joining of each 2D image to the resulting 3D form.

Object which we want to scan, has to be able to reflect the blue light fringe projection back to the camera system. It means that object which is shiny reflects the light too much because of scattering of incident light. For this reason, we use surface coating by titanium powder which allows correct reflection of light and contrast of the surface of the object.

As mentioned, our measured object was hard metal rod which is a semi product for cutting tool, e.g. end mill. At the Centre of Excellence of Five-Axis Machining of the Faculty of Materials Science and Technology in Trnava, Slovak University of Technology, are these hard metal rods used as a semi product for manufacturing of milling tools by WZS 60 Reinecker 5-axis grinding machine. In the experiment, the circular runout and total runout of hard metal rod was measured. This rod was clamped in chuck on which was stuck reference points in terms of experience where to put these points. One reference point was also on the circular plane on the rod because of clear positioning of this plane. Whole configuration of scanner, rotary table, chuck, measured object and reference points used in experiment is seen in the Fig. 1.

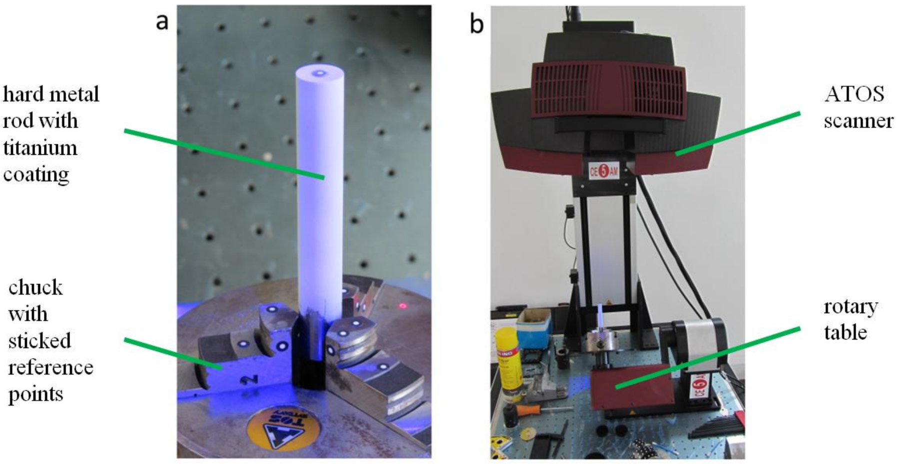

Fig. 1 Configuration of equipment used in experiment; (a) hard metal rod coated with titanium powder clamped in chuck; (b) ATOS scanner and rotary table with chuck and measured rod
Obr. 1 Konfigurácia zariadenia použitého pri experimente; (a) tyčka zo spekaného karbidu povlakovaná titánovým práškom upnutá v skľučovadle s nalepenými referenčnými bodmi; (b) 3D skener ATOS a rotačný stôl so skľučovadlom a meranou súčiastkou

2.3 Experimental work procedure

Experimental work was carried out at the Centre of Excellence of Five-Axis Machining at the Faculty of Materials Science and Technology in Trnava, Slovak University of Technology in Bratislava, where ATOS scanner is situated and used in educational and research processes. As mentioned above, two measuring volumes were used in the experiment. Therefore, each step described in this part of paper was carried out for both measuring volumes.

The first step was the installation and calibration of chosen measuring volume. Rotary table with calibration object was used in calibration process. After calibration, the object for scanning - hard metal rod, was coated with titanium powder using special pneumatic pump, subsequently, the rod was clamped into the chuck.

ATOS scanner runs with GOM ATOS Professional V7.5 software. There were set the parameters of digitization. Camera focus and the projector focus as well as the polarization filter for camera were adjusted for the best contrast of rod surface. The full resolution, normal exposition time as well as high quality of scan were adjusted. Position, angle and number of rotations of chuck with clamped rod situated on the rotary table in relation to measuring space, were set. Subsequently, digitizing was performed. Consequently, another steps were set, like deleting redundant scanned features and objects (e.g. chuck), standard mesh polygonization and postprocessing with more details, as recommended in [14, 15]. As a result from these steps the digital model of hard metal rod in the STL format was exported.

For the evaluation of measuring capability of 3D scanner was chosen the value of runout of the rod. Hard metal rod, as a semi product for cutting tool, has tolerance value of 0.06 mm for runout. Runout of rod was evaluated for whole rod (as total runout), and in five sections (as five circular runouts) which were constructed virtually in the software in defined distance (5 mm, 15 mm, 25 mm, 35 mm, 45 mm) from reference circular plane on the rod. To each this section was fitted one circle using Gaussian method of creation (least squares method) with 3 sigma used points (99,73% of obtained points at specific section on the surface used for evaluation and creation the circle). Finally, the circle was generated and checking of its runout was required. For obtaining of total runout value, the cylinder, using Gaussian method of creation, was generated for whole rod and checking of its total runout was required. Specified number of measurements (50 - in according to requirements determined by method of repeatability of measurements), exported models and obtained results, were performed. Fig. 2 shows the GOM Inspect V8 software which was used for working with data in terms of obtaining the circular runout value of the rod in five sections and for total runout value. In the figure are shown elements used for rod`s circular runout value obtaining in selected five virtual sections and for total runout of rod.

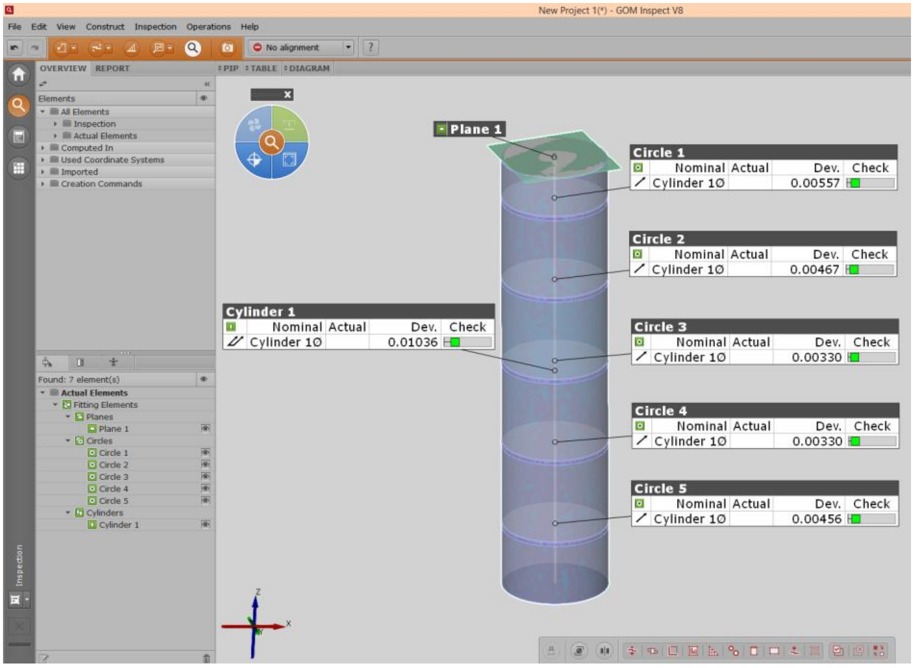

Fig. 2 GOM Inspect V.8 software with elements used for circular runout value obtaining in selected five virtual sections and for total runout value obtaining

Obr. 2 Softvér GOM Inspect V.8 so zobrazenými elementami použitými pre získanie hodnoty kruhového hádzania tyčky vo vybraných piatich rezoch a celkového hádzania

3 Evaluation of measuring device capability

Measuring device capability evaluation is one the statistical methods frequently used for assessment of a measuring systems in industry. Capability of device demonstrates functional capability of the device and the bias (accuracy) and repeatability (precision) of the measured data. Quality of the measured data is related to the statistical properties of repeated measurements obtained in stable conditions. This method of evaluation assumes a normal (Gaussian) distribution of measured data.

Steps for measuring device capability evaluation, as in [7, 8, 9, 16]:

1. Calculate the arithmetic mean

$$\overline{X_a} = \frac{1}{n}\sum_{i=1}^{n} X_i \tag{1}$$

where:
n...number of measurements,
X_i…*i*-th measured value.

2. Calculate the sample standard deviation

$$S_G = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(X_i - \overline{X_a}\right)^2} \tag{2}$$

3. Calculate the capability index

$$C_g = \frac{0.2T}{6S_G} \tag{3}$$

where:
T...given tolerance value.

4. Calculate the capability index for upper specification limit

$$C_{gkU} = \frac{\left(X_r + 0.1T\right) - \overline{X_a}}{3S_G} \tag{4}$$

where:
X_r... reference value (e.g. central value of the tolerance).

5. Calculate the capability index for lower specification limit

$$C_{gkL} = \frac{\overline{X_a} - (X_r - 0.1T)}{3S_G} \tag{5}$$

6. Determine the extended capability index

$$C_{gk} = \min(C_{gkU}; C_{gkL}) \tag{6}$$

If both of indices - C_g and smaller one from C_{gkU} or C_{gkL}, exceed the determined value 1.33, the measuring system is regarded as capable. Values of operative coefficients in formulas are selected in accordance with the methodology of Bosch company [7].

3.1 Three concepts of capability evaluation

Three concepts for each measuring volume (MV100 and MV170) were chosen.

First concept was the finding of average value of circular runout in five sections which were virtually constructed on each of 50 hard metal rod digitized model. From average value from each section, capability was evaluated.

Second concept was the finding of average value of circular runout from five circular runouts, which were virtually constructed on each of 50 hard metal rod digitized model. From average value of average circular runout of each rod, capability was evaluated.

Third concept was the capability evaluation from the average value of total runout from all 50 rods together.

In the Fig. 3 are schemes of three concepts of capability evaluation for both measuring volumes.

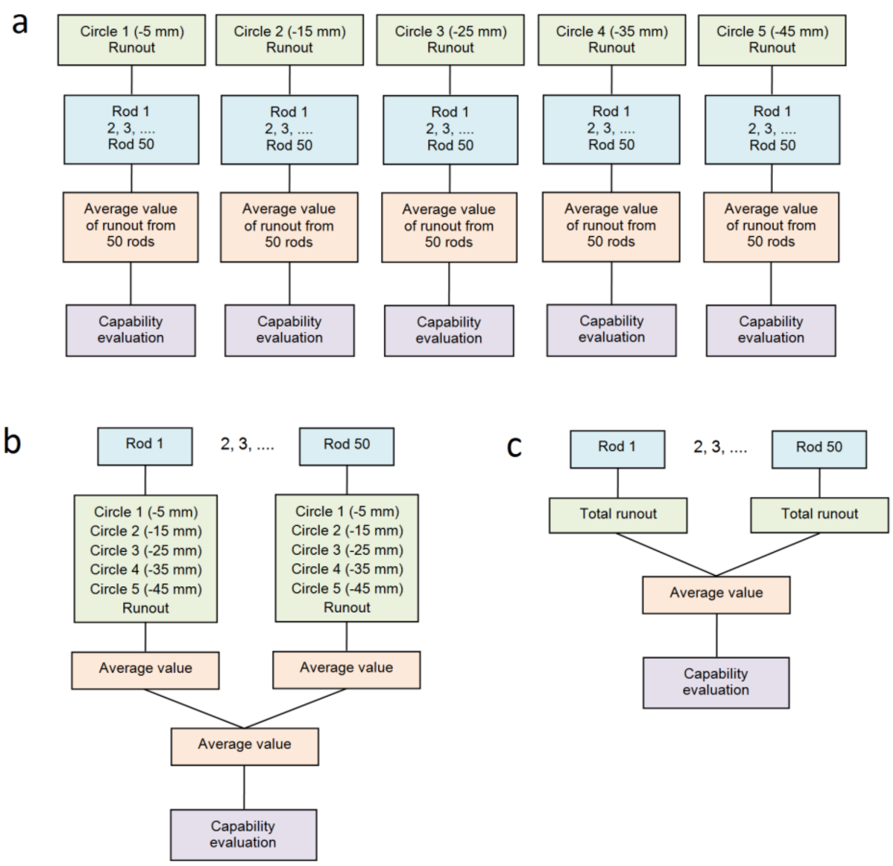

Fig. 3 Schemes of three concepts of capability evaluation; (a) capability evaluation for each circular runout, (b) capability evaluation for average circular runout, (c) capability evaluation for total runout

Obr. 3 Schémy troch konceptov pre vyhodnotenie spôsobilosti; (a) vyhodnotenie spôsobilosti pre každé kruhové hadzanie, (b) vyhodnotenie spôsobilosti pre priemernú hodnotu kruhového hádzania, (c) vyhodnotenie spôsobilosti pre celkové hádzanie

3.2 Capability evaluation results

Data obtained during 50 times of digitization of hard metal rod were evaluated in terms of equations mentioned above. Tab. 2 and Tab. 3 show calculated values of arithmetic mean, sample standard deviation and capability indices in accordance to three concepts of measuring device capability evaluation for both measuring volumes.

Tab. 2 Results of device capability evaluation for measuring volume MV100

Concept	Arithmetic mean $\overline{X_a}$ [µm]	Sample standard deviation S_G [µm]	Capability index C_g	Capability index for USL C_{gkU}	Capability index for LSL C_{gkL}	Extended capability index C_{gk}
Concept A Circle 1 (-5 mm)	5.89	1.27	1.57	7.90	-4.75	4.75
Concept A Circle 2 (-15 mm)	4.84	0.89	2.25	11.68	-7.18	7.18
Concept A Circle 3 (-25 mm)	4.57	0.94	2.12	11.09	-6.86	6.86
Concept A Circle 4 (-35 mm)	4.53	0.70	2.84	14.91	-9.22	9.22
Concept A Circle 5 (-45 mm)	5.54	0.91	2.19	11.11	-6.73	6.73
Concept B	5.07	0.71	2.83	14.57	-8.92	8.92
Concept C	10.40	1.45	1.38	5.90	-3.13	3.13

Tab. 3 Results of device capability evaluation for measuring volume MV170

Concept	Arithmetic mean $\overline{X_a}$ [µm]	Sample standard deviation S_G [µm]	Capability index C_g	Capability index for USL C_{gkU}	Capability index for LSL C_{gkL}	Extended capability index C_{gk}
Concept A Circle 1 (-5 mm)	14.13	1.80	1.11	4.05	-1.83	1.83
Concept A Circle 2 (-15 mm)	12.47	1.45	1.38	5.40	-2.65	2.65
Concept A Circle 3 (-25 mm)	10.19	1.07	1.87	8.03	-4.30	4.30
Concept A Circle 4 (-35 mm)	9.13	1.21	1.65	7.41	-4.10	4.10
Concept A Circle 5 (-45 mm)	7.02	0.90	2.23	10.76	-6.30	6.30
Concept B	10.59	1.13	1.77	7.49	-3.95	3.95
Concept C	17.79	1.80	1.11	3.38	-1.15	1.15

Analysis of measuring capability of ATOS 3D scanner with selected measuring volumes gives the results which allow us to consider this scanner, in general, as capable to provide acceptable results when measuring small and precise objects with narrow tolerance of geometrical characteristic of runout. The results gave us information that MV100 measuring volume is able to measure more accurate and precise than MV170 measuring volume. Lower value of arithmetic mean, variance of results, sample standard deviation as well as higher capability indices from various concepts are seen from results of MV100 in contrast to MV170. It means that these results are more near to real value of runout. It is due to higher density of captured points of MV100 measuring volume which represent the real surface of the rod. However, results of few concepts when using MV170 measuring volume show incapability of measuring. Therefore, here is need to realize some factors.

Firstly, ATOS scanner is not primary designed to scan and measure such small and precise objects. Zoller Genius 3s measuring device, for example, is designed exactly to tool measuring. Between these two devices is great difference of functional principle. ATOS uses digitization and triangulation, Zoller uses simple front and rear illumination of tool and focused edge detection. Selection of ATOS scanner for this experiment was deliberate because of pointing to suitability or unsuitability of really precise measuring of tools.

Secondly, the given tolerance of runout is not too wide. The rod manufacturer determined the tolerance value 0.06 mm for any type of runout (circular, total). It was determined in relation to application area of rod which is its usage as a semi product for manufacturing of milling tool.

Thirdly, the need of the rod`s surface coating with titanium powder due to better contrast of fringe projection, as well as no optimal ambient light conditions, may affect the results in tenths of microns.

4 Conclusion

The evaluation of the measuring capability of a measuring device is very important in the field of quality assurance. This paper deals with the possibility of measuring a small objects, namely hard metal rod which is a semi product for cutting tool, e.g. end mill manufacturing. The goal was the evaluation of the measuring capability of the GOM ATOS

Triple Scan II optical 3D scanner when measuring the geometrical characteristic of runout with using of various measuring volumes. To achieve this goal, obtaining the sufficient number of relevant values for evaluation of capability was necessary. Fifty digital models of rod were obtained in according to requirements determined by method of repeatability of measurements and measuring device capability evaluation. Three concepts of evaluation were chosen for each measuring volume. First concept was the finding of average value of circular runout in five sections which were virtually constructed on each of 50 hard metal rod digitized model. From average value from each section, capability was evaluated. Second concept was the finding of average value of circular runout from five circular runouts. From average value of average circular runout of each rod, capability was evaluated. Third concept was the capability evaluation from the average value of total runout from all 50 rods together.

Analysis of measuring capability of ATOS 3D scanner with selected measuring volumes gives the results that the scanner is, in general, capable to provide acceptable results when measuring small and precise objects with narrow tolerance of geometrical characteristic of runout. Selection of ATOS scanner for this experiment was deliberate because of pointing to suitability or unsuitability of precise measuring of tools.

From our experiment is seen the difference of results from both measuring volumes and difference of accuracy and precision between them, as well. This is a fact which predetermines the area of usage of MV100 and MV170 measuring volume. The factor of a tolerance zone value determination, which has great influence on capability consideration, depends on the specific practical requirements for the product, of its dimensions, shape, surface, as well as application area.

Finally, we can say that this scanner is accurate and precise device in terms of required area of usage. The major usage area of this scanner is a digitizing of medium sized and large sized objects from special applications where only a model of digitized object is needed, and a simple inspection like surface comparison of CAD model and model of digitized object with color deviation map is required. And here, the scanner is really sufficient and it provides acceptable results. For a medium sized objects with not too strict tolerances is this scanner appropriate to use and it is able to digitize these objects and measure the parameters very well.

We have outlined the metrological view on the abilities of ATOS scanner which has not been much exercised in conditions and requirements of our institute. At the same time, it will be the indicator about abilities of this scanner for owners of this type of measuring device and their customers with specific requirements. Further step will be focused to the deeper statistical analysis of ATOS scanner abilities in reverse engineering and measuring processes.

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Abstrakt

Názov: **Určenie spôsobilosti optického 3D skenera pri meraní geometrickej charakteristiky**

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Kľúčové slová: Meranie, spôsobilosť, opakovateľnosť, presnosť, 3D skener

Uvedená experimentálna práca sa zaoberá hodnotením spôsobilosti optického 3D skenera GOM ATOS Triple Scan II SO pri digitalizácii (meraní) malého objektu, konkrétne tyčky zo spekaného karbidu, ktorá je polotovarom na výrobu rezných nástrojov 5-osovým brúsením, napr. stopkovej valcovej frézy. Na posúdenie spôsobilosti zariadenia sa využilo meranie geometrickej charakteritiky hádzania. Spôsobilosť sa hodnotila pre dva rozličné meracie objemy skenera (MV100 a MV170) s využitím metodiky MSA (Measurement System Analysis). Parametre skenera sú uvedené v Tab. 1. Celá konfigurácia skenera, rotačného stola, skľučovadla, meraného objektu a referenčných bodov je na Obr. 1. Všetky získané dáta sa spracovávali a vyhodnocovali s využitím softvéru GOM Inspect V.8, zobrazený je na Obr. 2, kde sú tiež zobrazené elementy použité pre získanie hodnoty kruhového hádzania tyčky vo vybraných piatich rezoch a celkového hádzania. Pre vyhodnotenie spôsobilosti boli vytvorené tri koncepty. Prvý koncept spočíval v zistení strednej hodnoty kruhového hádzania meraného na piatich vyrtuálnych rezoch súčiastky vytvorených na každom jednom digitálnom modeli. Spôsobilosť sa vyhodnocovala pre každý rez zvlášť. Druhý koncept spočíval v zistení strednej hodnoty kruhového hádzania z piatich kruhových hádzaní meraných v prvom koncepte. Zo zistenej strednej hodnoty kruhového hádzania zo stredných hodnôt z každého jedného modelu sa vyhodnocovala spôsobilosť. Tretí koncept spočíval v analýze spôsobilosti využitím strednej hodnoty celkového hádzania všetkých 50 digitálnych modelov. Na Obr. 3 sú schémy troch konceptov pre vyhodnotenie spôsobilosti. Výsledky analýzy spôsobilosti sú uvedené v Tab. 2 pre merací objem MV100 a v Tab. 3 pre merací objem MV170. Z analýzy vyplýva, že skener možno považovať za spôsobilý poskytovať relevantné výsledky pri meraní malých objektov s relatívne úzkou hodnotou geometrickej tolerancie hádzania. Výsledky ukazujú rozdiel v presnosti a opakovateľnosti medzi dvoma porovnávanými meracími objemami. Objem MV100 vykazoval menšiu hodnotu aritmetického priemeru, variability výsledkov, smerodajnej odchýlky, ako aj väčšie hodnoty indexov spôsobilosti v porovnaní s MV170. To znamená, že objem MV100 vernejšie zachycuje skutočný stav tvaru a rozmerov súčiastky. Je to napr. z dôvodu vyššej hustoty zaznamenaných bodov, ktoré reprezentujú skutočný povrch súčiastky. Z výsledkov je taktiež možné zhodnotiť, aký veľký význam má predpisovanie hodnôt tolerancií a aký je ich vplyv významný pri posudzovaní kvality meradla. Uvedené výsledky a analýza meracích vlastností optického 3D skenera ATOS majú význam v oblasti výskumu a požiadaviek na Ústave výrobných technológii MTF STU.

Zpět