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Evaluation of Measuring Capability of the Optical 3D Scanner

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Abstract

The evaluation of the measuring capability of a measuring device is very important in the field of quality assurance. It is a part of a measurement system analysis. One of the measuring devices is the optical 3D scanner which is device for object digitization, in substance. 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. The issue was the evaluation of the measuring capability of the GOM ATOS Triple Scan II optical 3D scanner when measuring the dimensions, i.e. tool diameter, with using of different measuring volumes. Measuring of a small objects is often difficult due to ensuring the measuring repeatability and low bias. Capability evaluation was performed using statistical methods, namely indices which define the measuring device capability. The work contributed to the practical knowledge about abilities of ATOS optical 3D scanner in reverse engineering and measuring processes, and to the determination of its measuring capability.

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Keywords: measurement; capability; repeatability; bias; 3D scanner

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1. Introduction

Nowadays, non-contact measuring systems are raising in engineering metrology due to their efficiency when measuring a parts that could not be measured using coordinate measuring machines or could be measured very complicated. In contrast to the coordinate measuring machines are the optical scanners, for instance, less appropriate to play so wide and high precise metrological role. On the other hand there are applications where is more useful to use optical non-contact measuring systems instead of contact methods. When measuring small parts, optical

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measuring systems are very effective. For example, using of active triangulation scanning technique for shape investigation of worn cutting inserts, as in [1], measurement of wear process of milling tool based on optical method, as in [2, 3], dimensional analysis of cutting inserts using optical multisensory device, as in [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 in [5], or an example of application of optical scanning in the Reverse Engineering process with additive manufacturing - Rapid Prototyping, as in [6].

However, whether such a optical system is capable to provide relevant data, is the question. Measurement with a optical system requires a specific approach of the operator in preparing and optimizing the measurement conditions. Such devices can operate fully 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 example by standard deviation.

In practical engineering, the Measurement System Analysis (MSA) manual, is used to complete 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 is focused only on the gage, not on any other sources of variation. Two indices are used for assessment a measuring device capability, C_g and C_{gk}. This method uses index C_g to evaluate the repeatability (random error of the measurement system) and index C_{gk} to evaluate the bias (systematic error of measurement system). Capability indices compare the width proportion 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 mutual 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, not only a gage, represents share of measurement system variability, expressed as a percentage of tolerance field, in the total variance, as described in [10]. Researchers in [11] point to gauge measurement errors impacted the manufacturing capability estimating using empirical estimator. Analysis with usage of R&R study and ANOVA method in according to measuring process capability, is extensively referred in [12]. An overview of theory and practice on process capability indices for quality assurance, is widely described in [13].

Nomenclature

C_g	measuring device capability index
C_{gk}	extended measuring device capability index
C_{gkU}	capability index for upper specification limit (USL)
C_{gkL}	capability index for lower specification limit (LSL)
S_W	sample standard deviation
$\bar{X}_a$	arithmetic mean

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 - 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 on which were 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 Table 1.

Table 1. Parameters of ATOS scanner [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]. 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. Milling tools from these hard metal rods are produced by WZS 60 Reinecker 5-axis grinding machine at the Centre of Excellence of Five-Axis Machining at the Faculty of Materials Science and Technology in Trnava, Slovak University of Technology, where was our experiment carried out, also. In the experiment, diameter 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.

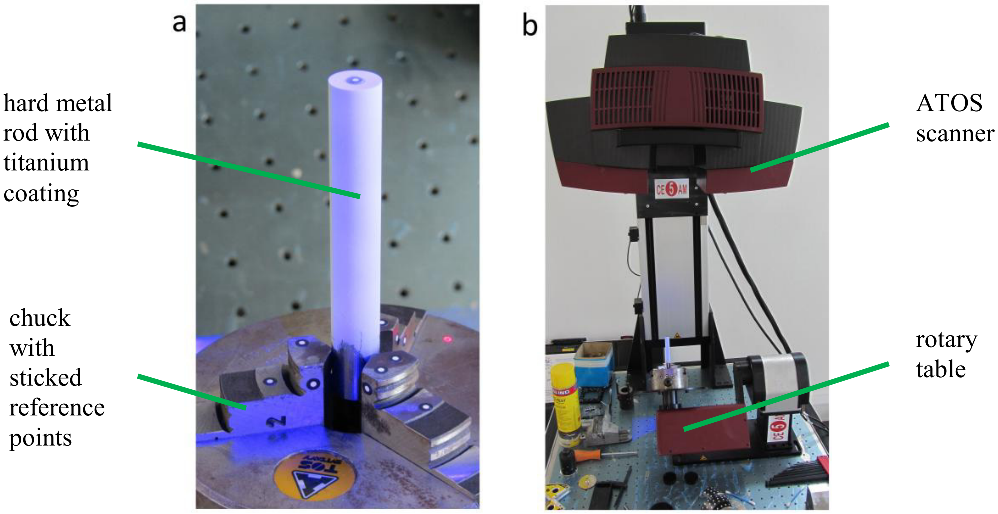


Fig. 1. Configuration of equipment used in experiment; (a) hard metal rod coated with titanium powder clamped in chuck; (b) ATOS scanner and rotary table with chuck and measured rod.

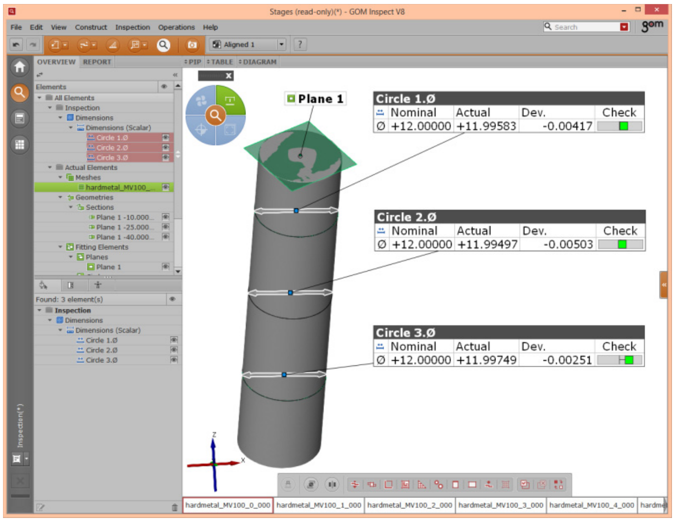
2.3. Experimental work procedure

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 diameter of the rod. Hard metal rod, as a semi product for cutting tool, has nominal diameter Ø12 mm with tolerance class h6 (upper specification limit = 0 mm, lower specification limit = 0.011 mm), as in [16]. Diameter of rod was evaluated in three sections which were constructed virtually in the software in defined distances (10 mm, 25 mm, 40 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 are used for evaluation and creation the circle). Finally, the circle was generated and checking of its dimension, i.e. the diameter of rod, was required. Diameter of rod was the result. 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 GOM Inspect V8 software which was used for working with data in terms of obtaining the rod diameter value. In the figure are shown elements used for rod diameter value obtaining in selected three virtual sections.



Circle 1.Ø

	Nominal	Actual	Dev.	Check
Ø	+12.00000	+11.99583	-0.00417	🟩

Circle 2.Ø

	Nominal	Actual	Dev.	Check
Ø	+12.00000	+11.99497	-0.00503	🟩

Circle 3.Ø

	Nominal	Actual	Dev.	Check
Ø	+12.00000	+11.99749	-0.00251	🟩

Fig. 2. GOM Inspect V.8 software with elements used for rod diameter value obtaining in selected three virtual sections.

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, 17]:

1. Calculate the arithmetic mean

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

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

2. Calculate the sample standard deviation

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

3. Calculate the capability index

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

T - given tolerance value

4. Calculate the capability index for upper specification limit

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

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

5. Calculate the capability index for lower specification limit

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

6. Determine the extended capability index

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

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. Two focuses on capability evaluation

Two ways of focus for each measuring volume (MV100 and MV170) were chosen. As mentioned above, diameter of rod was evaluated in three sections which were constructed virtually in software in defined distances (10 mm, 25 mm, 40 mm) from reference circular plane on the rod. Fifty digital models of rod were obtained in according to requirements determined by method of repeatability of measurements and measuring device capability evaluation.

First way of focus was the calculation of average value of rod diameter from three values, i.e. three sections constructed on each of 50 hard metal rod digitized model. From these averages from each model, capability was evaluated.

Second way of focus was the finding of average value of rod diameter for each section separately which was constructed on each of 50 hard metal rod digitized model. From average values from each section, capability was evaluated.

In the Fig. 3 are schemes of two ways of focus of capability evaluation for two measuring volumes.

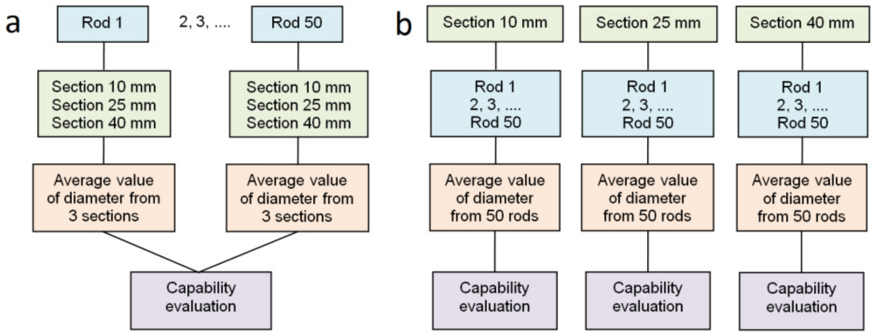


Fig. 3. Schemes of two ways of focus of capability evaluation; (a) capability evaluation for rods together, (b) capability evaluation for each section.

3.2. Capability evaluation results

Data obtained during 50 times of digitization of hard metal rod were evaluated in terms of equations mentioned above. Following Table 2. and Table 3. show calculated values of arithmetic mean, sample standard deviation and capability indices in accordance to two focuses on measuring device capability evaluation for both measuring volumes - MV100 and MV170. Hard metal rod, as a semi product for cutting tool, has nominal diameter Ø12 mm with tolerance class h6 (upper specification limit = 0 mm, lower specification limit = 0.011 mm).

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

Focus	**Arithmetic mean** [mm]	**Sample standard deviation S_W** [mm]	**Capability index C_g**	**Capability index for USL C_{gkU}**	**Capability index for LSL C_{gkL}**	**Extended capability index C_{gk}**
Focus A	11.99569	0.00063	0.58	-0.05	1.22	0.05
Focus B Section 10 mm	11.99573	0.00063	0.58	-0.07	1.24	0.07
Focus B Section 25 mm	11.99415	0.00059	0.62	0.82	0.43	0.43
Focus B Section 40 mm	11.99720	0.00063	0.58	-0.84	2.01	0.84

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

Focus	**Arithmetic mean** [mm]	**Sample standard deviation S_W** [mm]	**Capability index C_g**	**Capability index for USL C_{gkU}**	**Capability index for LSL C_{gkL}**	**Extended capability index C_{gk}**
Focus A	11.99496	0.00231	0.16	0.09	0.23	0.09
Focus B Section 10 mm	11.99280	0.00091	0.40	1.03	-0.22	0.22
Focus B Section 25 mm	11.99489	0.00060	0.61	0.40	0.83	0.40
Focus B Section 40 mm	11.99497	0.00057	0.64	0.37	0.91	0.37

Analysis of measuring capability of ATOS 3D scanner with selected measuring volumes gives the results, that this device is not capable to provide acceptable results when measuring such precise objects with such narrow dimensional tolerance. However, 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 function 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 scanned object was really narrow. For the rod diameter dimension range 10 - 14 mm with h6 tolerance class, the value of tolerance is only 0.011 mm. In our experiment we found, that if the rod manufacturer determined the tolerance class h8 with 0.027 mm tolerance value, our scanner will be capable when using MV100 measuring volume, because both of indices C_g and C_{gk} will be larger than determined value 1.33. On the other hand, when using MV170 measuring volume, the evaluation of Focus A and Focus B 10 mm shows incapability of the scanner. In the Focus B 10 mm are results near capability and if we use the h9 tolerance class with tolerance value of 0.043 mm, scanner will be capable. From results in the Focus A is seen that scanner is not capable, even if we use the h9 tolerance class. The results of capability evaluation after tolerance class editing to h8 for both measuring volumes are shown in Table 4.

Table 4. Capability indices when using h8 tolerance for rod diameter for both measuring volumes.

	MV100 Capability index C_g	**MV100 Extended capability index C_{gk}**	**MV170 Capability index C_g**	**MV170 Extended capability index C_{gk}**
Focus A	1.43	3.45	0.39	0.83
Focus B Section 10 mm	1.44	3.47	0.99	1.32
Focus B Section 25 mm	1.53	2.80	1.51	3.18
Focus B Section 40 mm	1.43	4.23	1.43	4.23

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, microns may be.

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. The issue was the evaluation of the measuring capability of the GOM ATOS Triple Scan II optical 3D scanner when measuring the dimensions, i.e. tool diameter with using of different 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. Two ways of focus for capability evaluation for each measuring volume were chosen. First way of focus was the calculation of average value of rod diameter from three sections. Second way of focus was the calculation of average value of rod diameter for each section separately. Analysis of measuring capability of ATOS 3D scanner gives the results, that this device is not capable to provide acceptable results when measuring such precise objects with such narrow dimensional tolerance. Selection of ATOS scanner for this experiment was deliberate because of pointing to suitability or unsuitability of really precise measuring of tools.

From our experiment seems the ATOS scanner as incapable to provide acceptable results when measuring the small, high precise objects with narrow value of dimensional tolerance. From the evaluation is clear how great is the influence of tolerance zone value determination. It depends on the specific practical requirements for the product, of its dimensions, shape, surface, as good as place of practical use. In our case it would be sufficient to have a wider tolerance zone for hard metal rod diameter. However, this would be in conflict with practical requirements.

Finally, despite the fact that the ATOS scanner is not capable in terms of our experiment we can say that it 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 measuring and capability evaluation of part`s shape characteristic and a metrological view on this issue to enrich the knowledge about ATOS scanner abilities in reverse engineering and measuring processes.

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