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THE COMPARISON OF DESTRUCTIVE AND NON-DESTRUCTIVE FORMS OF MEASUREMENT IN THE AUTOMOTIVE INDUSTRY

Nikola Skřivanová, Martin Melichar

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Abstract

The article focuses on the comparison of advantages and disadvantages of destructive and non-destructive forms of measurement in the automotive industry. X-ray, CT control system - Y. Cougar SMT has been used during the experiment, which allows non-destructive measurement and CMM - Vertex 311 UM, in which the measured dimensions are not always accessible and therefore cannot be measured without destructive intervention.

The purpose of the experiment was to verify the capabilities of these measuring machines and also to analyse the measurement system. The purpose was achieved in both cases These results were used as a basis for evaluating individual advantages and disadvantages of destructive and non-destructive forms of measurement on the above-mentioned machines.

Keywords: CMM; X-ray; CT; C_g, C_{gk} indexes; MSA

1. Introduction

Accurate measurement is an essential prerequisite for improving the quality of production in the automotive industry and it is one of the basic ways of obtaining quantitative information about the monitored quantity. It has become a fundamental prerequisite for trust in the exchange of goods and it is also one of the important conditions for efficient production. [1]

The research was based on the requirement of a testing laboratory of a company that produces components for the automotive industry. The current situation in the laboratory corresponds to the fact that the laboratory technicians do not have fixed rules for the selection of the machine. The technician chooses the measuring machine for inspection at his own discretion. The requirement of the testing laboratory was to assess the suitability of CMM (destructive form of measurement) and X-ray, CT control system (Non-destructive form of measurement) for measuring manufactured products. Therefore, the experiment described below was designed. The experiment is a part of the research. The results of the experiments will be used to elaborate a comprehensive methodology of the testing laboratory, which is a part of further research. The company is certified according to IATF 16 949.

The IATF 16 949 standard for the automotive industry makes it clear that if a customer requests any measurements of some of the final products from the manufacturer, the manufacturer is obliged to make the measurements. In case the conditions are not adequate, the manufacturer is obliged to provide a suitable alternative. [2]

This article describes an experiment which compares destructive and non-destructive dimensional measurements in the automotive industry using two representative machines. Non-destructive measurement consists in the ability to measure a product without destructive intervention if there are inaccessible dimensions.

This implies manufacturer cost savings regarding the destroyed and affected pieces as in the case of destructive measurement. Measurements on CMM often require destruction of the measured object. X-ray, CT measurement systems are increasingly being used in the automotive industry for non-destructive measurement. This technology has undergone considerable development over the years and has been successfully used not only in medicine, but also in non-destructive visual inspections and accurate measurements in the industrial sector. [3], [4], [5], [6]

The evaluated measuring machines are: CMM - Vertex 311 UM and X-ray, CT control system - Y. Cougar SMT, which allows measurement using X-ray photos or CT model. These measuring machines have their variables, for example: measurement speed, resolution, accuracy, repeatability, reproducibility, destructive/non-destructive form of analysis, etc. There are many factors. Within the experiment, the capability of these measuring machines was assessed using capability indices Cg, Cgk, and analysis of the measurement system MSA. The remaining factors will be part of further research. All measurements for the comparison of destructive and non-destructive measurements based on the experiment were performed with the participation of an employee of the accredited metrology laboratory of the Regional Institute of Technology, Faculty of Mechanical Engineering, University of West Bohemia.

2. Experiment description

One of the prerequisites for uniform and accurate measurement is the verification of the capability of the measuring system. Verification of the measuring system is used to ensure the quality of production. Its purpose is to assess the suitability of a measuring system for a specific application. As the cost of product accuracy keeps on rising, it is not only the production of accurate dimensions that is essential, but also a reliable and competent measurement process. All measurements within the experiment were performed under controlled conditions at 20 ± 1 ° C and 45 ± 1% humidity.

2.1. Measurement data for capability verification using capability indexes C_g C_{gk}

The capability of measuring instruments is verified by means of indices Cg, Cgk, so-called suitability of the measuring system to measure the monitored quality mark in the production or tolerance field. This method of validation was developed by Ford. The capability indices Cg and Cgk evaluate the measuring device in terms of bias and repeatability. The Cg index represents the meter's potential due to its variability and the Cgk index shows the meter's true capability. This method is mainly used for measuring devices where results are not influenced by human factors, such as automatic measuring machines and absolute gauges. [7], [8], [9], [10]

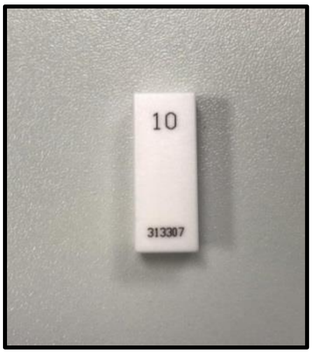

Fig. 1. Standard - ceramic gauge block 10mm

The following conditions must be observed when measuring the control standard [7]:

- One piece measured
- measurement is performed min. 30x by one worker
- one measuring device
- one measurement procedure
- subject to the same conditions
- in a relatively short period of time

Within this analysis, the standard (10mm ceramic end gauge) was repeatedly measured, see Fig. 1. The results are valuated by using the online software available from: http://trestik.cz/msa-spc-ford.

2.2. Measurement data for Measurement System Analysis (MSA)

The MSA Measurement System Analysis is an analytical method used to assess the capability of a measurement system and its suitability for specific applications. Requirements for this analysis appear in the automotive industry standards VDA 6.1 and IATF 16 949. It is also part of QS 9000 quality management methods such as Six Sigma or TQM. This methodology is well-proven and has long been recognized by customers. The outcome of the MSA analysis is the R&R parameter. In practice, it is the percentage of the initial tolerance specified by the customer, which the supplier "uses" owing to ambiguous measurement. [11], [12], [13]

MSA based on statistical measurement results assess whether the measuring system can provide repeatedly identical and correct results regardless of the worker, measuring device or procedure, the so-called system capability for the given application under the given conditions. The most used method is the R&R method, which performs evaluation in terms of repeatability and reproducibility. Verification of repeatability and reproducibility is based on repeated measurements of the actual product fulfilling the function of a standard. [12]

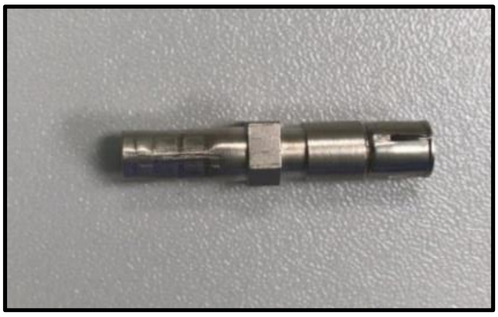

Fig. 2. Test specimen - copper tube

The following conditions must be observed when measuring an actual product [12]:

- 10 labelled samples measured
- measurement is performed repeatedly (3x) by three workers (90 measurements altogether)
- one measuring device
- one measurement procedure
- subject to the same conditions
- in a relatively short period of time

Within this analysis, a selected dimension of copper tube, which is part of the harness connectors manufactured for the automotive industry, was measured (Fig. 2.). The evaluation is carried out using the online software available from: http://www.trestik.cz/online-deznosti-zpusobilosti-meridel-metodou-rar.

3. Statistical processing

3.1 Evaluation of measured data for analysis using indexes C_g, C_{gk}

Measured values on CMM and X-ray, CT control system, which were measured by X-ray photo and CT model were evaluated using the above-mentioned online software for calculation of fitness indexes Cg, Cgk. As part of this analysis, the capability was experimentally sought for each measuring machine when the following condition is met:

$$Cg, Cgk > 1{,}33.$$

This condition is set by the automotive industry standard VDA 6.1. The measured data from individual measurements are in Tables 1., 2. and 3.

Measurement	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
Value [mm]	10,0021	10,0014	10,0018	10,0015	10,0017	10,0017	10,0020	10,0016	10,0017	10,0018
Measurement	**11.**	**12.**	**13.**	**14.**	**15.**	**16.**	**17.**	**18.**	**19.**	**20.**
Value [mm]	10,0019	10,0015	10,0015	10,0014	10,0016	10,0014	10,0016	10,0015	10,0016	10,0018
Measurement	**21.**	**22.**	**23.**	**24.**	**25.**	**26.**	**27.**	**28.**	**29.**	**30.**
Value [mm]	10,0015	10,0016	10,0016	10,0018	10,0016	10,0014	10,0014	10,0016	10,0017	10,0016

Table 1. Measured data for CMM (C_g, C_{gk})

Measurement	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
Value [mm]	10,0060	10,0060	10,0060	10,0060	10,0060	10,0060	10,0060	10,0060	10,0060	10,0010
Measurement	**11.**	**12.**	**13.**	**14.**	**15.**	**16.**	**17.**	**18.**	**19.**	**20.**
Value [mm]	10,0060	10,0060	10,0060	10,0060	10,0060	10,0030	10,0030	10,0060	10,0030	10,0060
Measurement	**21.**	**22.**	**23.**	**24.**	**25.**	**26.**	**27.**	**28.**	**29.**	**30.**
Value [mm]	10,0060	10,0060	10,0060	10,0030	10,0030	10,0060	10,0010	10,0030	10,0060	10,0060

Table 2. Measured data for RTG (C_g, C_{gk})

Measurement	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
Value [mm]	10,0100	10,0100	10,0000	10,0100	10,0000	10,0200	10,0000	10,0100	10,0100	10,0100
Measurement	**11.**	**12.**	**13.**	**14.**	**15.**	**16.**	**17.**	**18.**	**19.**	**20.**
Value [mm]	10,0000	10,0100	10,0100	10,0100	10,0000	10,0000	10,0100	10,0100	10,0100	10,0100
Measurement	**21.**	**22.**	**23.**	**24.**	**25.**	**26.**	**27.**	**28.**	**29.**	**30.**
Value [mm]	10,0100	10,0100	10,0100	10,0100	10,0000	10,0200	10,0100	10,0100	10,0100	10,0100

Table 3. Measured data for CT (C_g, C_{gk})

This analysis shows for which product tolerances these particular machines are eligible for measurement under VDA 6.1. The CMM is capable of measuring tolerances from ± 0.012 mm. When measured by X-ray, the machine becomes eligible at up to 5 times the tolerance value at ± 0.06 mm. Measurement using a CT model becomes eligible for measurements with tolerances in the order of tenths in particular up to ± 0.15mm. The results of this analysis are summarized in Table 4.

Measuring machine	Cg	Cgk	Limit tolerance	Suitable
CMM	4,6135	1,46094	> ±0.012	YES
RTG	2,44109	1,41041	> ±0.06	YES
CT	1,88442	1,36097	> ±0.15	YES

Table 4. Evaluation of capability verification analysis using indexes C_g, C_g

3.2 Evaluation of measured data for MSA analysis

In some cases, even at ideal Cg, Cgk index values, the measuring machine may fail to measure the actual product. This is due to, for example, a poorly accessible dimension, insufficiently trained personnel, etc. For this reason, a measurement system analysis (MSA) is performed. This analysis shows whether the measuring machine is able to measure a particular dimension of the product with the appropriate tolerance. For the positive eligibility check the following condition must be met:

$$\% R\&R < 10.$$

This condition is specified in the automotive industry standard VDA 6.1 and IATF 16 949. The measured data from the individual measurements are shown in Tables 5, 6 and 7.

Sample	Measured values by worker A[mm]			Measured values by worker B [mm]			Measured values by worker C[mm]		
1.	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600	6,9590	6,9590	6,9590
2.	6,9360	6,9360	6,9360	6,9360	6,9360	6,9360	6,9340	6,9340	6,9340
3.	6,9580	6,9580	6,9580	6,9580	6,9580	6,9580	6,9580	6,9580	6,9570
4.	6,9540	6,9540	6,9540	6,9540	6,9540	6,9530	6,9540	6,9540	6,9540
5.	6,9510	6,9510	6,9510	6,9520	6,9520	6,9520	6,9530	6,9520	6,9520
6.	6,9550	6,9550	6,9550	6,9550	6,9550	6,9550	6,9560	6,9560	6,9560
7.	6,9690	6,9690	6,9690	6,9690	6,9690	6,9690	6,9700	6,9700	6,9690
8.	6,9500	6,9500	6,9500	6,9500	6,9510	6,9500	6,9490	6,9490	6,9490
9.	6,9580	6,9580	6,9570	6,9560	6,9560	6,9560	6,9580	6,9570	6,9570
10.	6,9500	6,9500	6,9500	6,9510	6,9510	6,9510	6,9510	6,9510	6,9510

Table 5. Measured data for CMM (MSA)

Sample	Measured values by worker A[mm]			Measured values by worker B [mm]			Measured values by worker C[mm]		
1.	6,9618	6,9618	6,9618	6,9618	6,9618	6,9618	6,9618	6,9618	6,9618
2.	6,9230	6,9230	6,9230	6,9230	6,9230	6,9230	6,9230	6,9230	6,9230
3.	6,9588	6,9588	6,9588	6,9588	6,9588	6,9588	6,9588	6,9590	6,9588
4.	6,9536	6,9536	6,9536	6,9536	6,9536	6,9536	6,9536	6,9536	6,9536
5.	6,9513	6,9513	6,9513	6,9513	6,9513	6,9513	6,9513	6,9513	6,9513
6.	6,9538	6,9538	6,9536	6,9538	6,9538	6,9538	6,9536	6,9538	6,9538
7.	6,9572	6,9572	6,9690	6,9572	6,9690	6,9690	6,9690	6,9690	6,9572
8.	6,9487	6,9487	6,9486	6,9487	6,9487	6,9487	6,9486	6,9486	6,9487
9.	6,9562	6,9562	6,9562	6,9562	6,9562	6,9562	6,9562	6,9562	6,9562
10.	6,9490	6,9490	6,9490	6,9490	6,9490	6,9490	6,9490	6,9480	6,9480

Table 6. Measured data for RTG (MSA)

Sample	Measured values by worker A[mm]			Measured values by worker B [mm]			Measured values by worker C[mm]		
1.	6,9700	6,9700	6,9600	6,9700	6,9700	6,9700	6,9700	6,9600	6,9700
2.	6,9300	6,9300	6,9300	6,9300	6,9400	6,9400	6,9400	6,9400	6,9400
3.	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600
4.	6,9500	6,9500	6,9500	6,9500	6,9400	6,9500	6,9500	6,9400	6,9400
5.	6,9500	6,9500	6,9500	6,9500	6,9500	6,9500	6,9500	6,9600	6,9500
6.	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600
7.	6,9700	6,9700	6,9700	6,9700	6,9700	6,9700	6,9800	6,9800	6,9700
8.	6,9500	6,9400	6,9500	6,9500	6,9500	6,9500	6,9500	6,9500	6,9500
9.	6,9600	6,9600	6,9600	6,9600	6,9600	6,9600	6,9800	6,9800	6,9800
10.	6,9500	6,9500	6,9500	6,9600	6,9500	6,9500	6,9500	6,9500	6,9500

Table 7. Measured data for CT (MSA)

After evaluating the measurements using the online software, the above conditions were met. The measurement system was therefore considered acceptable. The summary of this analysis is in Table 8.

Measuring machine	Controlled dimension with appropriate tolerance [mm]	%R&R [%]	Suitable
CMM	7±0.2	0.22<10	ANO
RTG		1.13<10	ANO
CT		3.89<10	ANO

Table 8. Evaluation of MSA analysis

If the % R&R parameter was in the range of 10-30, the measurement system was conditionally compliant, so-called acceptable according to the importance of application, machine cost, repair, etc.

3.3 Summary of the results of the experiment

It is the CMM that performs the best within MSA and Cg, Cgk. However, this measuring machine, unlike X-ray and CT, has the disadvantage of having to destroy the product when measuring inaccessible dimensions. In the case of customer complaints, for example, the customer does not always give consent to disassemble the product. In this case, although the CMM is the most accurate, it is not always applicable to the purpose.

If customer consent is given or internal analysis is involved, the risk of product disassembly should be considered. X-ray measurement is suitable for products with significantly higher tolerance, but it is not necessary to disassemble the product in case of inaccessible dimensions. A problem could arise if the X-ray image cannot provide clear relevant product information, for example, when different objects overlap in the image or when higher resolution needs to be achieved. In such cases, the best solution is to scan a CT model that can provide all this information. However, according to the analysis results, CT model measurements can only be applied to products that have tolerances in the order of tenths of millimetres. Table 9 was created for the clarity of the use of individual measuring machines in terms of measuring range dependence on dimension accessibility.

Dimension accessibility ↓	**Tolerance [mm] →**			
	<0.012	**≥0.012 ∧ <0.06**	**≥0.06 ∧ <0.15**	**≥0.15**
Yes	/	CMM	CMM, RTG	CMM, RTG, CT
No	/	/	RTG	RTG, CT

Table 9. Table of measuring machines usage in terms of measuring range dependence on dimension accessibility

4. Conclusion

The research was based on the requirement of a testing laboratory of a company that produces components for the automotive industry. The requirement of the testing laboratory was to assess the suitability of the CMM (destructive form of measurement) and X-ray, CT control system (non-destructive form of measurement) for measuring the products produced. Using the suitability of these measuring machines makes the selection of a suitable measuring machine more effective, relief of excessively overloaded machines and more even work distribution. At the same time, the results of the experiment will be the basis for the development of a comprehensive methodology of the testing laboratory, which is part of further research.

This article deals with the comparison of destructive and non-destructive forms of measuring dimensions in the automotive industry. Within the experiment, a series of repeated measurements were performed on particular measuring machines (CMM, X-ray, CT). The measurements were performed equivalently on all the measuring machines while maintaining the same measurement conditions. Within the experiment, the capability of these measuring machines was verified using capability indices Cg, Cgk and the MSA measurement system was analysed.

The analysis of measurement systems MSA shows that all measuring machines are capable of measuring a specific automotive product. However, the best result was obtained by CMM, in which only 0.22% of the product tolerance is affected by the measurement.

Another part of the experiment was measuring the data to verify eligibility using indexes Cg, Cgk. As part of this analysis, the capability limitations for the VDA 6.1 automotive industry have been experimentally found for each measuring machine. After evaluating the measured data, it was found that the largest measuring range was shown by CMM. Next in line is X-ray.

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