COMPARISON OF CAPABILITY CALCULATIONS OF SURFACE ROUGHNESS MEASUREMENT PROCESSES IN AUTOMOTIVE INDUSTRY

Ágota DRÉGELYI-KISS[1], Árpád CZIFRA[2] and Béla PALÁSTI-KOVÁCS[3]
Bánki Donát Faculty of Mechanical and Safety Engineering,
Óbuda University, Népszínház u. 8, H-1081 Budapest, Hungary
[1]*E-mail: dregelyi.agota@bgk.uni-obuda.hu*
[2]*E-mail: czifra.arpad@bgk.uni-obuda.hu*
[3]*E-mail: palasti@bgk.uni-obuda.hu*

Abstract:
Besides dimensional and shape accuracy, eliability and life cycle of components produced in different ways highly depend on the quality of the processed surface. There are some automotive industrial parts where it is important to have appropriate surfaces. In these cases it is necessary to examine the measurement process for its suitability, for its capability.

The calculation methods of capability of measurement processes in automotive industry differ from each other. There are three main calculation methods: MSA, VDA 5 and the international standard, ISO 22514-7. During this research our aim was to compare the capability calculation methods in a case-study. Ten automotive parts are chosen to examine the behavior of the manufacturing process and to measure the required characteristics of the measurement process being evaluated. The measurement uncertainty of the measuring process is calculated according to the VDA 5 and ISO 22514-7, and MSA guidelines.

In this study the conformance of a measurement process in an automotive manufacturing process is determined, and it is shown what are the similarities and the differences between the used methods.

Keywords: Measurement of surface roughness, Capability of measurement processes, Automotive industry

1. INTRODUCTION

There are serious requirements in automotive industry to evaluate the measurement processes. The significant or so-called SPC-parameters of an automotive part have to be measured in an appropriate and capable way. The significant parameters are defined in the Control Plan. The measurement of these parameters is compulsory in the field of automotive suppliers. It has to be verified that the measurement process and measurement device is capable to show the deviations within a specification range related to the significant parameters.

In this article two automotive parts were chosen. Some surface roughness parameters are significant; therefore measurement capability analysis was performed to evaluate the measurement processes. Three main calculation methods were used [1-3], and the capability parameters were modified in such a way that they could be used in case of surface roughness measurement processes where there are only one-side specification limits for the significant characteristics. Furthermore, the purpose of this research is to determine the main factors which affect the measurement results, and calculate measurement uncertainty values for the effects.

2. MATERIALS AND METHODS

Several surface roughness parameters of two automotive parts were measured to evaluate and compare the measurement uncertainty during the measurement process. The first part is a roller (Fig. 1), the second type is a vane automotive part (Fig. 2). Both parts were produced by metal powder sintering technology. The critical surface roughness and waviness parameters are represented in the drawings.
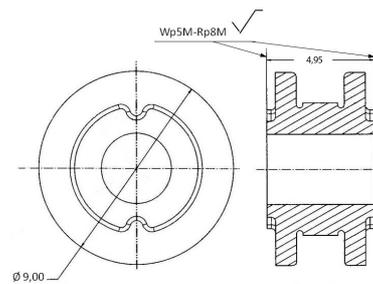

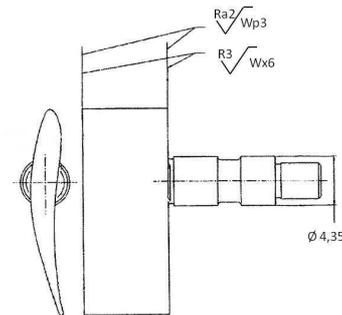Fig. 1: Technical drawing of the roller with special characteristics

Fig. 2: Technical drawing of the vane with special characteristics

Measurements were performed using a Mahr-Perthometer roughness measurement instrument with MFW-250:1 stylus and MahrSurf XCR-20 evaluation software.
The parameters related to surface roughness measurement were: in case of roller: $l=4 \cdot 2.4$ mm, $\lambda_c=0.8$ mm, in case of vane: $l=5.6$ mm, $\lambda_c=0.8$ mm according to dimensions of parts and ISO 4288.

In the course of the measurements of the two automotive parts the following roughness and waviness parameters were determined: Ra, Rp, Wp [4]; R, Wx [5].

3. MODIFIED CAPABILITY CALCULATIONS

In the course of the measurement process capability analysis the *GRR*% value or the capability ratio (Q_{MP}) can be calculated according to the automative industrial guidelines (MSA and VDA 5) [1, 2] or the ISO 22514-7 standard [3]. The calculations are based on the combined standard measurement uncertainty related to the measurement process (u_{MP}) and the specification.

In case of surface roughness measurement there are only upper specification limits for the special characteristics therefore it has to be modified the formulaes in the following ways:

$$GRR\% = \frac{u_{MP}}{\frac{1}{3}(U - \bar{x})} \cdot 100 = \frac{GRR}{\frac{1}{3}(U - \bar{x})} \cdot 100 \qquad (1)$$

where U is the upper specification limit, $\bar{x}$ is the mean value. For all calculations a 99.73% confidence interval was used (according to MSA[1]).

$$Q_{MP} = \frac{k \cdot u_{MP}}{U - \bar{x}} = \frac{U_{MP}}{U - \bar{x}} \qquad (2)$$

where k=2, because the expanded uncertainty (U_{MP}) is based on an approximate 95% confidence interval (according to [2] and [3]).

The recommended limit for the *GRR*% value and the Q_{MP} value is 30%. It can be seen that MSA has more strict condition for the measurement process evaluation.

The modified capability index is:

$$C_{MP} = \frac{6(U - \bar{x})}{3 \cdot u_{MP}} \qquad (3)$$

It is recommended that C_{MP} value exceeds 1.33 [3].

4. EXPERIMENTS

Design of experiments was prepared to analyse the uncertainty components related to the measurement process. Ten parts were chosen from the production process in both cases, for the roller and the vane, the measurements were performed by 2 operators in three measurement places (within the part) and 3 repetitions were made.

4.1 Experiments for the roller measurements

Two significant characteristics (*Rp* and *Wp*) have to be measured in the roller automotive part. In Fig. 3 the mean values of the different places and different operators with 95% confidence intervals for *Rp* and *Wp* parameters can be seen. The results show that between places there are large deviations which are comparable with the within places range. Similarly, there is difference between the average measurements of the operators but it does not seem to be large.

In Fig. 4 the reproducibility of the measurements is illustrated. There are large within part deviations in both cases, and the pattern of the average values is similar in case of both operators. This shows that the reproducibility of the measurements is good.
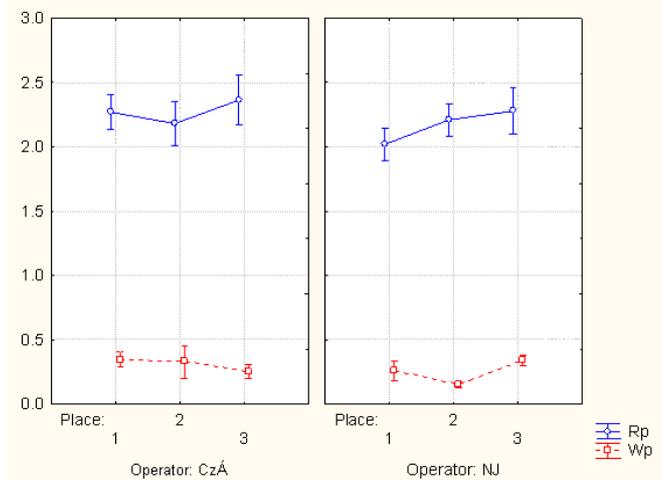

Fig. 3: Operator and place interaction in the examination of the roller (vertical bars denote 0.95 confidence intervals)
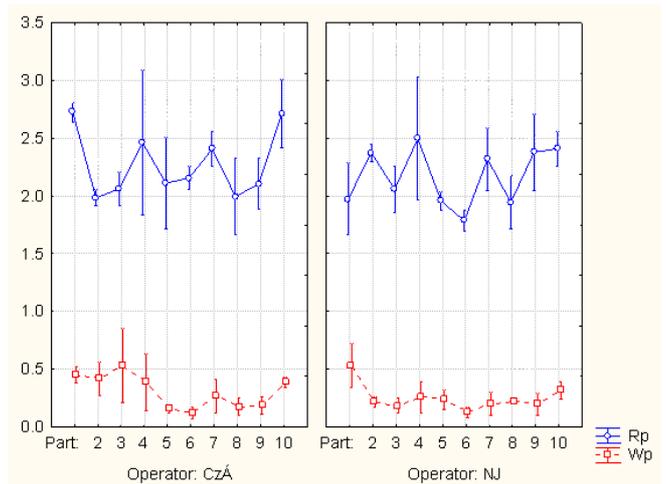

Fig. 4: Operator and part interaction in the examination of the roller (vertical bars denote 0.95 confidence intervals)
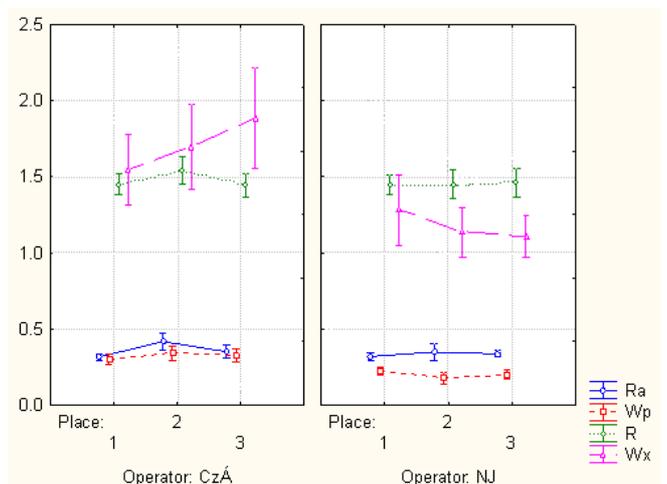

Fig. 5: Operator and place interaction in the examination of the vane (vertical bars denote 0.95 confidence intervals)

4.2 Experiments for the vane measurements

Four surface roughness and waviness parameters (*Ra, Wp, R and Wx*) were measured during the experiments in case of vane automotive parts. It can be stated (Fig. 5) that the place factor has a large effect on the results, especially in case of Motif parameters (*R, Wx*). The mean values of the operators are similar in cases of *Ra* and *Wp*, but differ from each other in cases of *R* and *Wx*. This pattern is illustrated in Fig. 6.
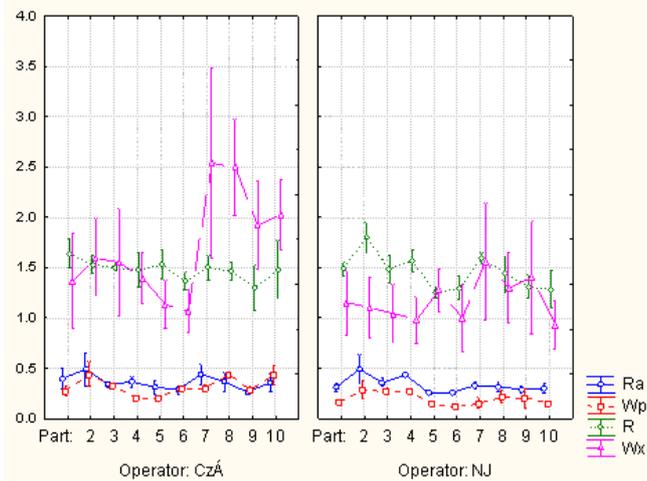

Fig. 6: Operator and part interaction in the examination of the vane (vertical bars denote 0.95 confidence intervals)

5. RESULTS AND DISCUSSION

ANOVA analysis was made in order to determine the components of measurement uncertainty. The built-up model is as follows:

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_{k(j)} + \alpha\beta_{ij} + \alpha\gamma_{k(ij)} + \varepsilon_{l(ijk)} \quad (4)$$

where *y* is the measured values, α_i is the random effect of the ith operator, β_j is the random effect of the jth part, $\gamma_{k(j)}$ is the random effect of the kth place within a jth part, ε is the experimental error.

The standard uncertainty of the measurement process is as follows (the effect of the temperature, linearity and stability are negligible):

$$u_{MP} = \sqrt{\sigma_\alpha^2 + \sigma_\beta^2 + \sigma_\gamma^2 + \sigma_{\alpha\beta}^2 + \sigma_{\alpha\gamma}^2 + \sigma_\varepsilon^2} \quad (5)$$

where σ^2s are the corresponding variance components.

5.1 Results for the roller

The results of the ANOVA for roller automotive part show that all effects are significant at 95% level except for the operator and the part in case of both dependent variables (*Rp* and *Wp*). The components of variance can be found in Table 1. It can be seen that the place has large impact on the measurement results, as well as the interactions related to the operator.

Table 1: Components of variance for roller (in μm^2, the significant effects (at 95% level) are bolded)

Effect	*Rp*	*Wp*
Operator (α)	0.00000	0.00000
Part (β)	0.00000	0.00285
Place(Part) (γ)	**0.11256**	**0.01338**
Operator•Part ($\alpha\beta$)	**0.04786**	**0.00756**
Operator•Place ($\alpha\gamma$)	**0.00817**	**0.00874**
Error (ε)	0.04700	0.01442

The standard uncertainty of the measurement process and the calculated capability parameters for the roller are summarized in Table 2. It can be stated the measurement capability values fulfill the requirements in all cases.

Table 2: Capability results for the measurement process of the roller

	Rp	*Wp*
u_{MP} [μm]	0.4643	0.2010
U [μm]	8	5
$\bar{x}$ [μm]	2.2203	0.2788
GRR%	24.10%	13.34%
Q_{MP}	16.07%	8.90%
C_{MP}	2.49	4.50

5.2 Results for the vane

Four roughness and waviness parameters were determined during the measurement of the vane parts. The ANOVA results show that operators and parts have no significant effects on the measurement results only in case of waviness parameters (*Wp* and *Wx*) for the operators. The components of variance can be seen in Table 3.

Table 3: Components of variance for vane (in μm^2, the significant effects (at 95% level) are bolded)

Effect	*Ra*	*Wp*	*R*	*Wx*
Operator (α)	0.00001	**0.00663**	0.00000	**0.12477**
Part (β)	0.00073	0.00000	0.00000	0.02893
Place(Part) (γ)	**0.00878**	**0.00382**	**0.02612**	**0.09175**
Operator•Part ($\alpha\beta$)	**0.00123**	**0.00476**	**0.01090**	**0.07139**
Operator•Place ($\alpha\gamma$)	**0.00061**	**0.00086**	**0.00133**	**0.02591**
Error (ε)	0.00207	0.00211	0.01569	0.23128

The standard uncertainty of the measurement process and the calculated capability parameters for the roller are in Table 4. It can be seen that the capability of measurement process in case of Motif paramerers does not fulfill the requirements.

Table 4: Capability results for the measurement process of the vane

	Ra	*Wp*	*R*	*Wx*
u_{MP}[μm]	0.1127	0.1349	0.2324	0.7383
U [μm]	2	3	3	6
$\bar{x}$ [μm]	0.3480	0.2614	1.466	1.4421
GRR%	20.46%	14.77%	**45.46%**	**48.60%**
Q_{MP}	13.64%	9.85%	**30.31%**	**32.40%**
C_{MP}	2.93	4.06	**1.32**	**1.23**

5.3 Comparison of the capability studies

Two automotive parts were chosen to estimate the capability of the measurement process. Relative variance components for each part can be seen in Fig. 7 and Fig. 8.
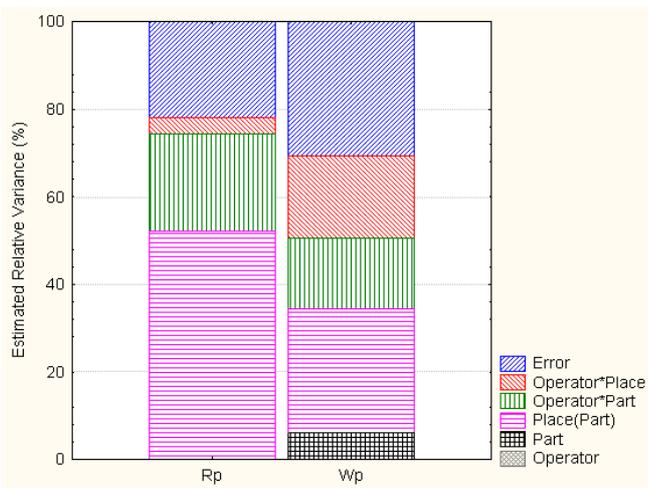

Fig. 7: Relative variance components (in percent) of the measurement process for roller
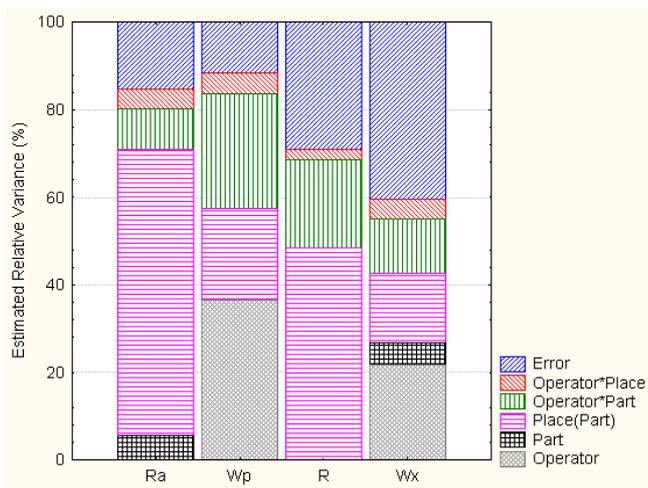

Fig. 8: Relative variance components (in percent) of the measurement process for vane

The results show that there are difference between the roughness and the waviness parameters. In case of roughness parameters the relative variance of the place is larger than in case of waviness parameters.

The roughness is sensitive for the local environment of the manufacturing process (tools or the present state of the process), while the waviness depends on rather of global factors (such as vibration and rigidity of the machine).

The effects of the operators which are related to the reproducibility of the measurement process are small comparing with the other variances. The effect of place factor and the interactions are important parts of the capability analysis of a surface roughness and waviness measurement process.

To decrease within part variation (i.e. between places) more measurement points could be examined and during the measurement process the average values of the surface roughness or waviness can be calculated. In case of repeated measurements during the control the measurement uncertainty decreases and the capability of the measurement process may fulfill the requirements.

Comparing the MSA with VDA 5 guidelines it can be stated that the American automotive industry has stricter limit for the same measurement process than the German or the ISO 22514-7 standard.

6. CONCLUSION

The measurement evaluation and measurement incertitude of surface roughness differs from what is of general practice in measurement engineering. In specifying surface roughness parameters, it is important on which part of the component the measurement is conducted, as surface inhomogeneity is substantial, compared to the uncertainty of measurement [6]. Furthermore the effects of the interactions (Operator•Part and Operator•Place) have significant role, therefore these factors can not be neglected in the course of surface measurement studies.

During surface roughness and waviness measurements modified capability indices are suggested for using the generally accepted parameters and limits.

ACKNOWLEDGEMENTS

REFERENCES

[1] QS 9000 – Measurement System Analysis, 4th Edition, 2010

[2] VDA 5, "Prüfprozesseignung", 2nd Edition, 2010

[3] ISO 22514-7, "Statistical methods in process management - Capability and performance – Capability of measurement processes", 2012

[4] ISO 4287/1: "Geometrical Product Specifications (GPS) – Surface texture: Profile method - Terms, definitions and surface texture parameters", 1997

[5] ISO 12085:" Geometrical Product Specifications (GPS) -- Surface texture: Profile method -- Motif parameters", 1996

[6] G.N. Tóth, Á. Drégelyi-Kiss, B. Palásti-Kovács: "Analysis of the microgeometric parameters of cut surfaces", *Pollack Periodica* 8:(02), in press, 2013