XVII International Scientific Conference on Industrial Systems (IS'17)
Novi Sad, Serbia, October 4. – 6. 2017.
University of Novi Sad, Faculty of Technical Sciences,
Department for Industrial Engineering and Management
Available online at http://www.iim.ftn.uns.ac.rs/is17

Measurement system analysis in production process

Biserka Runje
(Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, Zagreb, biserka.runje@fsb.hr)
Amalija Horvatić Novak
(Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, Zagreb, amalija.horvatic@fsb.hr)
Andrej Razumić
(Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, Zagreb, andrej.razumic@gmail.com)

Abstract

A quality of measurement system is just one in a series of production system parameters that influence functionality and final look of the product. For better control, and improvement of production processes, quality measurement system is needed to measure the characteristics of the process. This paper describes the procedures for the measurement system analysis in the manufacturing process and mathematical background of implemented steps. Analysis of the measurement system is different from case to case, and depends on the number of operators, the number of measured parts and number of replicates. In order to facilitate analysis of the measurement system, it is necessary to know and to understand its possibilities with strong accent on reliability.

Key words: *measurement system analysis, reproducibility, reliability*

1. INTRODUCTION

Measurement system analysis (MSA) is a study which quantifies the sources of variation that influence the measurement system [1]. MSA is also defined as an experimental and mathematical method of determining how much the variation within the measurement process contributes to overall process variability [2]. There are 2 main types of measurement system analysis which depend of the type of data being collected using the measurement system. Measurement system analysis methods are used to analyse measurement systems for continuous and attribute data. It is important to mention that all elements of a measurement system (gages, standards, operators, software, measurement equipment, procedures, environmental components, as well as others) can affect the variation of results and contribute to the measurement system capability. Capability of the measurement system can be characterized by quantifying its accuracy and precision. The accuracy is defined as a closeness of agreement between a measured quantity value and a true quantity value [3]. The accuracy of the measurement system has three components: bias, linearity and stability. Precision is defined as closeness of agreement between indications or measured quantity values obtained by replicate measurements on identical or similar objects under specified conditions [3]. The precision of the measurement system has two components: repeatability and reproducibility. A Gage R&R Study (GR&R) is a specific type of measurement system analysis which evaluates measurement system precision ie. estimates the combined measurement system repeatability and reproducibility.

Repeatability EV (equipment variation) is defined as a closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement (same procedure, same operator, same measuring instrument used under the same conditions, same measuring spot, repeated within a short time interval) [3]. It determines the influence of measuring instrument in the variation of the system.

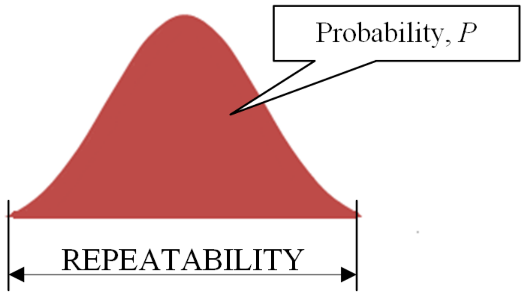

Figure 1. Repeatability

Reproducibility (appraiser variation) AV is defined as the closeness of the agreement between the results of the same measurand carried out under changed conditions of measurement, where these changed conditions may include principle of measurement, method of measurement, operator, measuring instrument, reference standard, location, conditions of use or time [4]. It determines the influence of operator within the system variation.

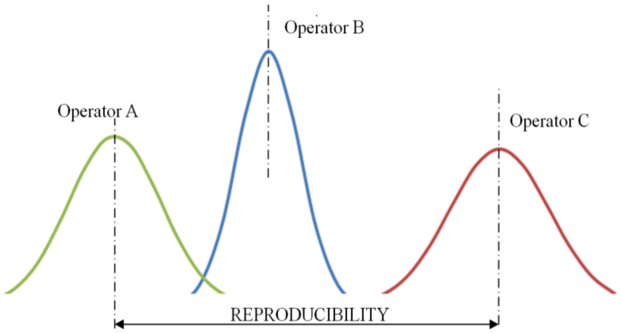

Figure 2. Reproducibility

The importance of measurement system analysis is essential for production process quality check in:

- Determination of components for calculating measurement process variation and evaluating acceptability for production process quality checks.
- Installation of new equipment.
- Comparison of measurement characteristics of different measurement systems.
- Determination of systematic errors.
- Comparison of measurement characteristics before and after the repair of measurement equipment.

Dimensional measurements in production process are conducted in order to determine conformity or nonconformity of product. Besides the information about measured object, the results of dimensional measurements are a prerequisite for the analysis of the measuring system in the production process. This paper will assess the measurement system for three different cases:

- Capability evaluation of measurement system with one measured object and one operator,
- Capability evaluation of measurement system with one measured object and more operators,
- Capability evaluation of measurement system with multiple objects and multiple operators.

2. CAPABILITY EVALUATION OF MEASUREMENT SYSTEM WITH ONE MEASURED OBJECT AND ONE OPERATOR

This model of evaluations shows the impact of measuring instrument inside the measurement system. The approach of using one object - one operator system evaluation is used in the beginning phase of analysing the measurement system, with aim of determining the influence of the measuring instruments, while negating other variation sources. In this case, the measurement system capability is determined through two indices: *Cg* (repeatability) and *Cgk* (repeatability and bias). These are calculated according to following expressions [5]:

$$Cg = \frac{K/100 \cdot T}{L \cdot s} \quad (1)$$

$$Cgk = \frac{K/200 \cdot T - |\bar{x}_g - x_m|}{L/2 \cdot s} \quad (2)$$

Where:

K - percentage of tolerance field (commonly 20 %)
T - tolerance field
s - estimated standard deviation of measurement results
L - the number of standard deviations representing the desired process width (usually 6 or 4)
$\bar{x}_g$ - arithmetic mean of measurement results
x_m - reference value

With given criteria:

1. The variation due to the measurement process should fall into the range of 20 % (± 10 %) of the tolerance field around the reference value.
2. $Cg \geq 1.33$; $Cgk \geq 1.33$
3. $\frac{\text{Measuring instrument resolution}}{T} \cdot 100 \leq 5\%$

3. CAPABILITY EVALUATION OF MEASUREMENT SYSTEM WITH ONE MEASURED OBJECT AND MULTIPLE OPERATORS

Capability evaluation of measurement system with one measured object and multiple operators is performed by comparing multiple samples with ANOVA analysis, each of which represents a basic set. Analysis of variance (ANOVA) is one of the standard statistical methods for estimating the measurement system and can be used to measure error measurement as well as other sources of data variability in the measurement system study. In the ANOVA analysis, the variance can be divided into four categories: parts, operators, interaction between parts and operators, and error due to repeatability.

4. EVALUATION OF MEASUREMENT SYSTEM WITH MULTIPLE OBJECTS AND MULTIPLE OPERATORS

In the case of evaluating measurement system with multiple objects and multiple operators, several combinations for conducting measurements are possible. Therefore, evaluation of measurement system can be made in case when each operator measures its own object, in case when only one operator measures every object (nested), or evaluating measurement system where one or more conditions are present, which implies the presence of more than two measurement factors (operator, measuring instrument and measured object), which is referred to as expanded GR&R measurement system capability evaluation. Figure 3 and 4 shows difference between crossed and nested gage R&R study [6].

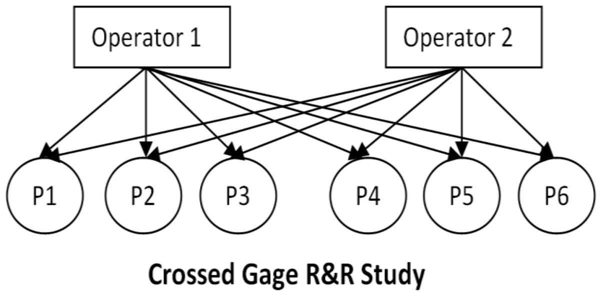

Figure 3. Crossed gage R&R

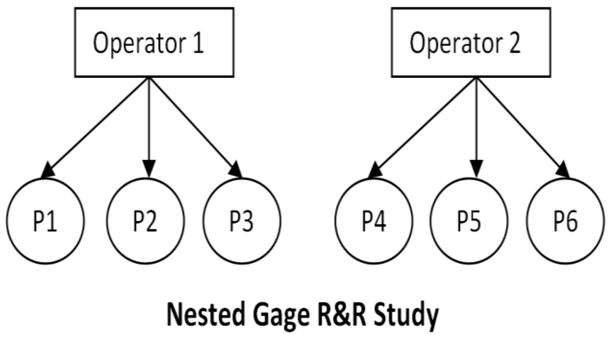

Figure 4. Nested gage R&R

The three stated analyses also differ in the approach used while evaluating repeatability and reproducibility of the system. The first analysis evaluates *R&R* using mean averages and ranges $(\overline{x} - R)$ or the ANOVA, while the other two methods use only ANOVA to evaluate *R&R*.

4.1. G*R&R* analysis - crossed

R&R crossed is most commonly used method for evaluating repeatability and reproducibility of the measurement system. It can be done with two approaches: one is ANOVA and the other is method of mean averages and ranges$(\overline{x} - R)$. Figure 5 presents schematic overview of *R&R* crossed analysis.

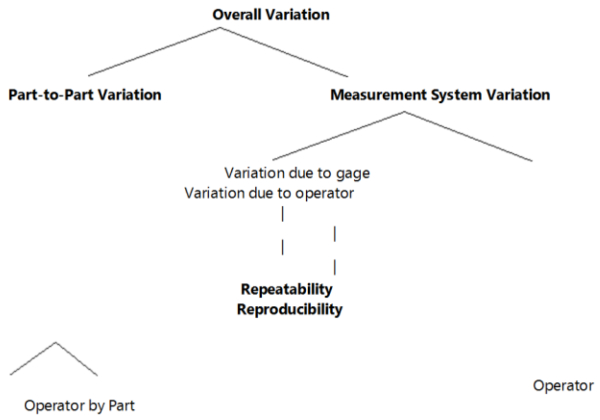

Figure 5. Schematic overview of *R&R* crossed analysis

4.2. G*R&R* analysis - nested

R&R nested analysis is used for evaluating repeatability and reproducibility of the measurement system when each sample is measured by only one operator, and only once [7]. For example, it is used for destructive measurements which are characterized by the object being completely destroyed or altered so much that its purpose is changed. The measured feature is altered after the first measurement. Examples include car crash tests, where the vehicle is after the test completely wrecked, and cannot be further used for driving. These tests are normally very expensive so they are not done often. The evaluation is done using ANOVA method. Figure 6 presents schematic overview of *R&R* nested analysis.

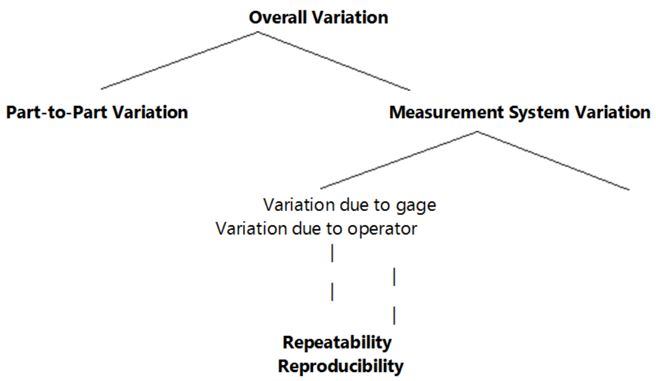

Figure 6. Schematic overview of *R&R* nested analysis

4.3. G*R&R* analysis - expanded

This analysis is used when multiple factors affecting the measurement system are to be evaluated. Besides usual factors, the operator and the object, some other factors are taken into account. *R&R* evaluation is done using the ANOVA method. Figure 7 presents schematic overview of *R&R* expanded analysis.

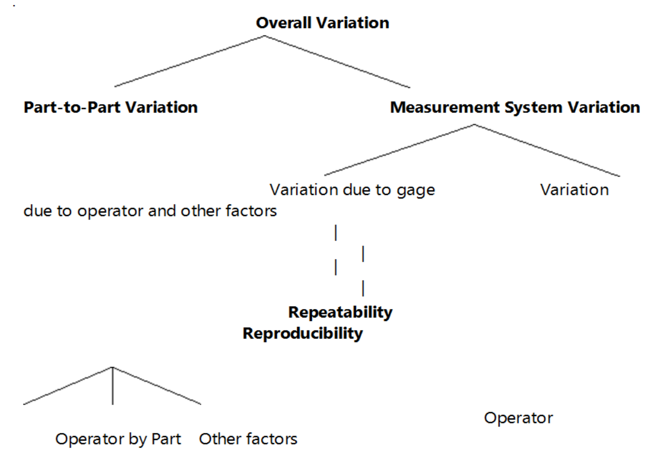

Figure 7. Schematic overview of *R&R* expanded analysis

The gage R&R analysis helps to determine:

- Weather the variability of the measurement system is small compared to variability of the process.
- How much the different operators affect the variability of the system?
- How much the equipment affects the variability of the system?
- Weather the system is capable of recognizing different parts.

Measurement system capability represents share of measurement system variability *R&R* expressed as percentage of total variation *TV* or tolerance field *T*, i.e. share of measurement system variance in the total variance [8,9].
Expressions for calculating measurement system capability are as follows:

$$\text{Measurement system capability} = GR\ \&\ R\ /TV \cdot 100\% \quad (3)$$

$$\text{Measurement system capability} = GR\ \&\ R\ /T \cdot 100\% \quad (4)$$

Criteria for assessing quality of measurement system *R&R* in the tolerance field *T* or total variation *TV* are provided in Table 1, and criteria for assessing quality of measurement system *R&R* for contribution percentage are provided in Table 2 [7].

Table **1.** Criteria for assessing quality of gage *R&R* in the tolerance field *T* or total variation *TV*

% *T*, % *TV*	**Gage *R&R***
< 10	Acceptable
10 – 30	Borderline
> 30	Unacceptable

Table 2. Criteria for assessing quality of gage *R&R* for contribution percentage.

Contribution, %	**Gage *R&R***
< 1	Acceptable
1 – 9	Borderline
> 9	Unacceptable

5. CONCLUSION

When assessing quality of a measurement system with multiple objects and multiple operators, the information about variability in the measurement system, caused by measurement objects, operators, or measuring instruments is gained. With this method, contribution of each component can be determined, and shown if the measurement results are accurate and precise, repeatable and/or reproducible. An important method for assessing quality of a measurement system is evaluation of measurement system with one measured object and one operator. It is often used in the beginning of a measurement system evaluation, because it shows the impact of the measuring instrument, i.e. the instrument itself is the source of variation in measurement system. By analysing the measurement system with one object and more operators, it is possible to get data about repeatability and reproducibility of measurement results. With known standard deviation of its parts, the quality of the whole system can be assessed. To conclude it should be noted that a high-quality and reliable measurement system is also one of the element necessary for maintaining quality in many activities and processes in industry, as well as in everyday life.

5. REFERENCES

[1] Emilio L. Cano, Javier M. Moguerza Andres Redchuk, Six sigma with R, New York 2012

[2] Measurement System Analysis – MSA available at: https://www.isixsigma.com/dictionary/measurement-system-analysis-msa/ (accessed: 15 July 2017).

[3] JCGM 200:2012 International Vocabulary of Metrology - Basic and general concepts and associated terms (VIM)

[4] NIST Technical Note 1297: *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, available at: http://www.pitt.edu/~jdnorton/teaching/1702_jnrsnr_sem/docs/Reproducibility/reproducibility.html (accessed: 16 July 2017).

[5] Methods and formulas for Type 1 Gage Study, available at: https://support.minitab.com/en-us/minitab/18/help-and-how-to/quality-and-process-improvement/measurement-system-analysis/how-to/gage-study/type-1-gage-study/methods-and-formulas/methods-and-formulas/, (accessed: 10 July 2017).

[6] Difference between crossed and nested Gage R&R, available at: http://blog.minitab.com/blog/michelle-paret/a-simple-guide-to-gage-randr-for-destructive-testing, (accessed: 10 July 2017).

[7] Gorman, D. and Bower, K.M. (2012). "*Measurement system analysis and destructive testing*", Measurement systems, available at: https://www.google.hr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0ahUKEwiT5b__5ZTVAhURmbQKHZU7AwkQFggoMAE&url=https%3A%2F%2Fwww.minitab.com%2FuploadedFiles%2FContent%2FNews%2FPublished_Articles%2Fmeasurement_system_analysis_destructive_testing.pdf&usg=AFQjCNFhVIRJzgCTkhTaAO3CLgi4jSbNcw&cad=rja, (accessed: 10 July 2017).

[8] Runje, B., Baršić, G. and Alar, V. (2010), "*Role of Gage R&R in estimation of process capability*". 14th Interantional Research/Expert Conference, TMT 2010.

[9] Runje, B., Medić, S., Kondić, Ž., Alar, Ž. and Tunjić, Đ. (2012). "*Statistical process control of fire-resistant coating production based on thickness measurements*", Tehnički Vjesnik-technical Gazette, Vol.18, No.3, pp.589-593.