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PROBLEMS OF APPLICATION OF MEASUREMENT SYSTEM ANALYSIS (MSA) IN METALLURGICAL PRODUCTION

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This paper lists the most fundamental problems related to the application of measurement system analysis (MSA) in metallurgical production and outlines ways of solving them. Based on the real measurements it was found, that the width of the confidence interval constructed for the value of combined gage repeatability and reproducibility (GRR) can be reduced (and thus the reliability of the GRR value can be increased) more by raising the number of trials than by increasing the number of samples. The basic assumption for the use of analysis of variance (constant variance and the occurrence of outliers) can be verified by using the proposed multiple box and whisker plot.

Key words: measurement, system, application, metallurgical production, confidence limit

INTRODUCTION

The most important condition for companies to be successful in the current global market is competitiveness, the level of which is affected by many factors. In the case of huge multinational companies, competitiveness can be partly based on their market share and goodwill. Small and young firms may base their success primarily on creativity and high rate of innovations [1]. However, no matter what the strategy of increasing competitiveness and maintaining it is, providing products and services of as high a quality as possible is the most fundamental factor of market success for all the aforementioned companies. To comply with this notion as much as possible, it is necessary to build up well a functioning quality management system. This system can be built on many concepts, including sectoral standards, such as QS 9000 or VDA, concepts based on the standard ISO 9001, ISO/TS 16949 or Model of Excellence EFQM. Whatever concept is chosen by a company, every quality management system should be found on and continuously developed on the basis of several fundamental principles.

For the principles to be applied correctly in practice, and this particularly concerns the last two principles, it is imperative that effective and correct decisions be found on deep data and information analyses. In the case of production processes, these facts are represented by measured data on all the observed parameters of quality of a product or service [2]. Abundance of quality data, provided only by a quality measurement system, is an important prerequisite for sound quality planning, management and improvements in this case.

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MEASUREMENT SYSTEM ANALYSIS

The standard covers requirements related to systems of measurement management, confirmation of measuring instruments and provision of evidence of conformity with metrological requirements, and it also contains guidelines on use and continual improvement of this system, in accordance with the standard EN ISO 9004:2010. As far as measurement system analysis is concerned, the standard contains a significant requirement that performance characteristics demanded for the intended use of the process of measurement must be identified and quantified. Consequently, satisfying the requirements of the standard may facilitate achieving compliance with requirements on management of the process of measurement contained in the standard ISO/TS 16949:2009, for instance.

The quality of a measurement system can be evaluated by several methodologies [3]. The automotive industry suppliers, which mostly come from metallurgical and engineering industry, much more often use and apply the MSA methodology - Measurement System Analysis [4]. The study that is performed most often is the study of combined repeatability and reproducibility (GRR) of measurement system MSA Handbook (AIAG, 2010) describes three methods used for evaluating these studies. They are Range method, Average and range method and Analysis of variance. The average and range method (A&R) is most commonly used for the assessment of measurement system repeatability and reproducibility in practice. The required data are obtained by repeated measurements of product samples realized by various appraisers. It uses a defined procedure which includes both numeric and graphical evaluation of repeatability (EV) and reproducibility (AV). On the basis of their values, it is possible to calculate the combined repeatability and reproducibility (GRR) according to the relation:

$$GRR = \sqrt{(EV)^2 + (AV)^2} \quad (1)$$

The percentage share of GRR in the total variation and the number of distinct categories (ndc) are used as the criteria of the measurement system acceptability. They are calculated using the relations:

$$\%GRR = (GRR \,/\, TV) \cdot 100 \quad (2)$$

$$ndc = 1{,}41 \cdot (PV \,/\, GRR) \quad (3)$$

where *TV* denotes total variation and *PV* stands for parts variation. A measurement system is considered fully acceptable when % GRR value is lower than 10 % and, at the same time, ndc value is at least 5. The last, fourth edition of the MSA manual stresses increasingly the importance of the evaluation of repeatability and reproducibility using analysis of variance (ANOVA). As far as this method is concerned, you can divide the total variation into repeatability (EV), reproducibility (AV), parts variation (PV) and the interaction between appraisers and parts (INT). In this case, the combined repeatability and reproducibility is calculated as follows [5, 6].

$$GRR = \sqrt{(EV)^2 + (AV)^2 + (INT)^2} \quad (4)$$

SPECIFICS OF MSA IN METALLURGICAL INDUSTRY

Implementation and evaluation of analyses of measurement systems may be confronted with various specifics in some industrial sectors or types of production, and metallurgical industry is no exception. On the basis of personal experience, run analyses and interviews with personnel responsible for implementation and evaluation of analyses of measurement systems, specific/problematic areas that can affect results of such analyses were defined.

A group of factors that affect the quality and precision of the indicators resulting from the GRR analysis in the first place are the values of parameters which enter the GRR analysis. A combination of the values of these parameters fundamentally affect the quality and precision of the percentage proportion of the GRR, related to the total variability, and the number of distinct categories (ndc). Since the value ndc depends to an extent on the value of GRR (Equation 3), we shall focus on the possibilities of increasing the precision of this value [7]. Three fundamental parameters of the GRR analysis affect the total number of measurements: the number of measured samples, the number of operators taking the measurements and the number of trials. Since the number of operators taking the measurements is usually fixed, the total number of measurements is mostly dependent on the remaining two parameters. The authors of the last, fourth edition of the MSA methodology tried to improve the quality of the resulting values by tightening the requirement for the minimal number of samples (it was raised to 10 from 5) and for the recommended number of samples (this was increased to 15 from 10). This requirement, however, contradicts the practical experience which suggests that it is hard to gather even the originally recommended number of samples in many metallurgical processes or products. This raises the question of whether it would be possible to obtain the values of the GRR analysis of the same or higher quality by increasing the number of trials. Since the quality of the resulting values of the GRR analysis, and the value of the GRR itself or its point estimate, can be evaluated by the width of confidence intervals, a series of simulations and measurements were performed, and the aim was to assess the width of the confidence interval constructed for the value of GRR [8], depending on changing values of the parameters that enter the GRR analysis. Measurements performed on nuts were utilized as entry data. The height of the nuts was the measured parameter. The results were obtained for the various number of samples (2 - 15) and various number of trials (2 - 10). To express analytically the dependence of the distance between the upper bound of the GRR confidence interval and its point estimate on the number of samples and repetitions, a nonlinear regression analysis was applied (Equation 5). It was found that in the case of two operators, the dependence is of the form:

$$d_{U,GRR} = 7{,}782 + 598{,}243 \cdot n^{-1{,}229} \cdot r^{-0{,}838} \quad (5)$$

where $d_{U,GRR}$ is the distance between the upper bound of the GRR confidence interval and its point estimate /%, *n* is the number of trials and *r* is the number of samples. The extent of the dependence is very good, given that the correlation index equals 0,996 and all the parameters of the model are statistically significant at α = 0,05 significance level. Comparing the results obtained, the implication is that the distance in question can be reduced (and thus the reliability of the GRR value can be increased) more by raising the number of measurement repetitions than by increasing the number of samples (Figure 1).

ANOVA

As was mentioned in the introductory part of the paper, analysis of variance (ANOVA) is used at present to assess repeatability and reproducibility of measure-

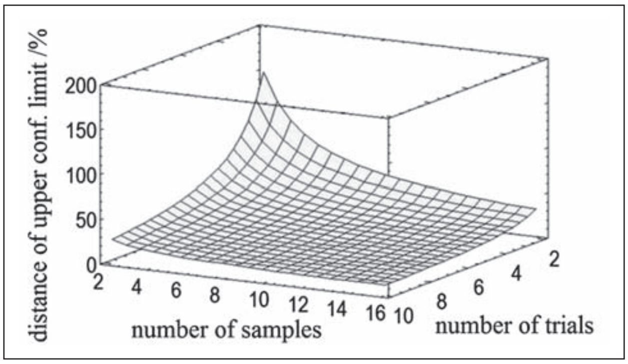

Figure 1 Response surface of the distance of upper GRR confidence limit from its point estimate

ments. The method has its advantages, described in a greater detail in [6,9], for instance, though it is also necessary to keep in mind the conditions this method is based on. As is generally known, analysis of variance relies on certain theoretical assumptions, just like other statistical methods which represent modelling techniques. This fundamental type of regression assumes, as is also known, that measurements to be analysed or modelled come from normal distributions, they are all independent and the normal distributions are characterized by the same variance. Provided that the assumptions of analysis of variance are not violated severely, the statistical method still works very well, and ranks among the very best statistical methods. The conditions that need not be adhered to strictly relate to the assumption of normality and constant variance. What is crucial, however, is that the measurements, based on which analysis of variance is to be carried out, must be statistically independent, i.e. one has to deal with mutually independent random samples.

Unlike the car industry, where the produced components are often measured with highly precise measuring instruments or 3D measuring systems, the metallurgical industry often has to carry out measurements of larger products with less sophisticated measuring instruments and under production conditions [10]. To ensure that the evaluation of acceptability of a measurement system worked out by analysis of variance was as precise and reliable as possible in this case, as well, it is necessary to assess whether the uniformity of the used measurement system is good enough. This property of the system reflects the aforementioned requirement that the variance should be constant, because it represents change in repeatability over the normal operating range (homogeneity of repeatability). To get an idea about whether the uniformity of the measurement system is acceptable (constant variance), some of the graphical tools of the GRR analysis can be exploited. One of the most suitable tools of this kind is a proposed graph picturing box and whisker plots that are constructed for all measurements of individual samples (Figure 2). An application of the box plot to real data shows that the variance of the measured values is sufficiently close to being constant, and so the given measurement system possesses the property of having a suitable uniformity.

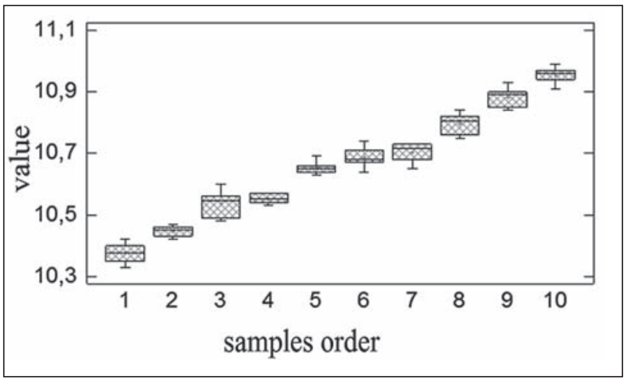

Figure 2 Multiple box and whisker plot

The graph also shows that the measured values obtained for each sample are not burdened with outliers.

CONCLUSION

An increase in quality of the GRR analysis through a higher number of trials provides, in the case of metallurgical industry, a less cumbersome way of acquiring reliable analysis of measurement system repeatability and reproducibility. The proposed multiple box and whisker plot complements other tools mentioned in the MSA methodology. The analysis of the graphical tools should be an integral part of the GRR analysis evaluation. The presented results and proposed graphical tools may contribute to a more successful application of measurement system analyses not only in metallurgy.

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