THE CAPABILITY EVALUATING OF INDUSTRIAL MEASUREMENT SYSTEMS

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Abstract − A usefulness of the best known and widely recommended methods and procedures of measurement systems capability determination is evaluated. A new method is proposed. This method allows correcting the capability index of measurement systems as the capability index of production process is being improved.

Keywords: industry, measurement systems, capability evaluating

1. INTRODUCTION

The industrial measurement systems are being used to measure specific quality attributes of products and their production processes.

The results of these measurements become a basis for decisions about processes controlling in order to prevent from making products either defective or non-according to the technical specification requirements.

There are no perfect measurements systems (comprehended as set methods, instruments, measured object, standards, personnel and environment) therefore the results of measurement always include systematic and random errors.

The measurement errors distort numerical values, which are being used to create control charts for process stability monitoring, to calculate indexes of process capability (C_p, C_{pk}) or to evaluate conformity of tested product's parameter value with a technical specification requirements

Essential diagnostic variables, which are being distorted by measurement errors, may lead to false decisions about industrial processes controlling an-as a result-my cause a considerable economical loss.

From economical and professional point of view, to reasonably minimize the probability of false decisions, manufacturers should use adequately matched measurement systems. That means the systems which cost is acceptable and their measurement capability index (calculated by specified method and including an influence of systematic and random errors), does not exceed an acceptable level of false decision probability.

In the industrial practice, various method of selection and evaluation of measurement system capability are being used and developed. Most of those methods are based on the determination of percentage share of measurement systems parameter (such as: resolution, linearity, bias and variability) in the range of process variability or tolerance zone of product's characteristic.

One type of the measurement results variability, defined as a measurement capability, is usually determined by *R&R* (repeatability and reproducibility) analysis. This method allows taking to consideration a combined influence of systematic and random errors. Nevertheless, it is possible to use other methods and procedures adjusted to the particular purpose and environment of the production tests.

2. METHODS AND PROCEDEURES

Many-years experience in the evaluating of the industrial measurement systems capability has led to the publication of a number of international standards [1], [2], [3], [4] and professional guidelines [5], [6], [7], [8], [9]. They include detailed descriptions and practical examples of estimating the measurement systems capability indexes. Those guidelines also encompass criteria of acceptance of the industrial measurement systems regarding to the statistical processes controlling and evaluating of the product's conformity with a technical specification requirements.

All those standards and guidelines together with the 'International Vocabulary of Basic and General Terms in Metrology' [10] and the 'Guide to the Expression of Uncertainty in Measurements' [11] make up a complete set of elaborated and internationally agreed recommendations. It is very helpful in collecting and interchanging the results of different experiences obtained in various industrial applications. This kind of professional discussion allows developing methods and procedures and, as a result, systematically improving the quality of the products and the customer satisfaction in different countries.

A detailed analysis of above mentioned standards and guidelines shows continuous efforts to better define basic terms such as: uncertainty, performance and capability of measurement systems. However, there is a significant diversity of methods and procedures depending on the industry branch. Since many years the automotive industry has been elaborating and developing the Measurement Systems Analysis (*MSA*) guideline. The latest edition is widely recognized as a compendium of metrological knowledge and a set of precisely described procedures, justified with practical examples and extensive bibliography. The guidelines of particular automotive corporations [8], [9]

and MSA-basing software producers [7] contain similar methods of measurements systems assessing. Those methods can be put in particular order, as shown in Table I. This order reflects a practical sequence of their application starting from the incoming inspection of a new system (including its stability determination). The last stage of the assessment is the *R&R analysis* of the measurement system working in the real production environment.

TABLE I. Methods of measurement capability evaluating applicable in the automotive industry.

Step	The purpose of examination	Applied statistical method
1	**Stability** determining	**Range&Average** analysis
2	**Bias** determining	**Range&Average** analysis
3	**Linearity** determining	**Regression** analysis
4	**Repeatability & Reproducibility** $\sigma_{R\&R}$ determining	**Range&Average** analysis **ANOVA** analysis

A particular guidelines [5], [6], [7], [8], [9] recommend somewhat different acceptance criteria of the industrial measurement systems. In every case those criteria are based on the relative measurement capability. Its value is calculated as a ratio of the width variability of measurement results (influenced by systematic and random factors) to the width variability of currently examined production process or to the tolerance zone of the product's characteristic. A relative measurement capability *GRR* (also called as a measurement capability index) may be presented as a mathematical formula:

$$GRR_{VP} = \frac{k \; x \; \sigma_{R\&R}}{k \; x \; \sigma_P} \qquad (1)$$

where

      k = 5.15 for a 0,99 confidence level

or

      k = 6 = 2x3 for a simplified calculation

      σ_P - standard deviation of a production process

or

$$GRR_T = \frac{2x3 \; x \; \sigma_{R\&R}}{T} \qquad (2)$$

where

$$T = \left| USL - LSL \right|$$

USL - Upper Specification Limit
LSL - Lower Specification Limit

Applying the formula (1) for determining of the relative measurement capability (which is a base for the acceptance of the industrial measurement system) has a long-term tradition. However, it may cause a lot of ambiguities whilst examined production process has not been stabilized yet. It is recommended therefore [7], [13] to use a formula (2) in which a width variability of measurement results [6 x $\sigma_{R\&R}$] is related to the constant value of the tolerance zone (*T*) of the product's characteristic.

A majority of the guidelines recommends a value $GRR_T \leq 0,2$ or $\%GRR_T \leq 20\%$ as a criterion of the final acceptance of the industrial measurement system. Such a criterion appears to be very clearly justified. Simple calculations [6] shows that the results obtained from the measurement system with relative capability value $GRR_T \leq 0,2$ may be applied to determining a production process capability index (C_P) with no need for the calculation of correcting values. The above-described basic R&R analysis method has occasionally been adapted to specific cases [18], [19].

Simultaneously, another method called PMAP (Process Measurement Assurance Program) has been developed [12]. Contrary to R&R method (basing on randomly selected product samples) PMAP uses specially matched working standards or reference materials. Their numerical values are being established and periodically checked in calibration laboratories. Such way of standards verification allows monitoring and systematically improving measurement systems capability through long-term assuring of stability of a measurement error reference lines in real production environment.

The PMAP method does not solve, however, an important problem indicated in MSA guideline [6], which consist in the need for improving measurement systems capability as the capability of production process is being improved. Such an a approach is particularly useful for '6 Sigma' strategy where the production process capability index (C_p) is being changed gradually from the typical value 1,33 to the final value 2, whilst the tolerance zone (*T*) of product's characteristic remains constant.

In the field of measurement capability evaluating, different kinds of problems occur in such industries as chemical and pharmaceutical. They use complex measurement systems based on reading result values from the calibration function prepared shortly before testing products or processes. A validity and application range of this function should be statistically verified by particular procedures [14], [15], [16]. There have also been worked out separate procedures of quantifying uncertainty for analytical measurement [17].

3. A NEW METHOD PROPOSAL

Taking to consideration the need for solving the problem of improving measurement systems capability as the capability index of production process is being improved, a new method of calculating of relative measurement capability GRR_{VPS} is proposed. In this method measurement results variability is related not to the tolerance zone (T) of product's characteristic but to the variability of production process standard $2x3\sigma_{PS}$.

Similarly to the tolerance zone, the standard process variability is a constant value and may be calculated by following formula:

$$C_{PS} = \frac{T}{2x3\sigma_{PS}} \qquad (3)$$

where:

σ_{PS} - standard deviation of production Process Standard

converting (3) we obtain:

$$2x3\sigma_{PS} = \frac{T}{C_{PS}} \qquad (4)$$

Assuming that proposed measurement capability index may be expressed by formula:

$$GRR_{VPS} = \frac{2x3\sigma_{R\&R}}{2x3\sigma_{PS}} \qquad (5)$$

by putting it into (5) (4) a correlation of a new index GRR_{VPS} with usually recommended one GRR_T is obtained:

$$GRR_{VPS} = \frac{2x3\sigma_{R\&R}}{T} x C_{PS} \qquad (6)$$

which results as:

$$\boxed{GRR_{VPS} = GRR_T \ x \ C_{PS}} \qquad (7)$$

The expression (7) allows calculating a required value of measurement capability index GRR_T when the improvement of process capability index is ordered. Such procedure may be helpful in pursuing *'6 Sigma'* level of production quality. A capability index for this standard and target process equals $C_{PS} = 2$. Applying the commonly used criterion $GRR \leq 0,2$ but replacing GRR index by GRR_{PS} (obtained by new method) the value of the index calculated by the usual method is $GRR_T \leq 0,1$.

In the industry practice such a result should become a basis for the decision o purchasing a new measurement system characterized by better measurement capability.

Table II. presents the effects of applying proposed method in a strategy of achieving *'6 Sigma'* production quality level, which is controlling to the standard process with capability index $C_{PS} = 2$.

Table II. The effects of applying the new method for achieving *'6 Sigma'* system

Kind of Process Standard	Process Standard Capability Index	**New** Measurem. Capability Index	**Old** Measurem. Capability Index
$\longrightarrow$	C_{PS}	GRR_{VPS}	GRR_T
normal	**1,33**	0,2	**0,154**
advanced	**1,6**	0,2	**0,125**
'6Sigma'	**2**	0,2	**0,100**

In Table II. it is clearly proved that applying the proposed method of calculating the relative measurement capability index stimulates a replacement of the currently working system for the better one, even though the tolerance zone of product's characteristic remains constant. A process capability index, however, is getting improved.

In author's opinion, it seems to be purposeful to combine the proposed new approach with the *PMAP* [12] method. Firstly, it should result in making a criterion of measurement system acceptance dependent on the value of process capability index. Secondly, a properly maintained set of working standards (applied in *PMAP* method) would assure a precise determining of the value $3x\sigma_{R\&R}$ in real production environment.

From a theoretical point of view, above-presented proposition is not comprehensive, even though it combines advantages and usefulness of two widely recognized methods: *R&R analysis* and *PMAP*. It is necessary to pursue intensive efforts to work out universal procedures basing on the acceptable probability level of qualification errors (type I and II) instead of relative measurement capability index *GRR*. Such an approach could entail a possibility of using trueness and precision measures [4] for the final acceptation of measurement systems. It would be a universal solution for all industry branches, regardless of applied measurement scales, kinds of tolerance limits (one-sided or two-sided) and quality control methods (based on attributes or variables). A detailed justification of this thesis can be found in [20].

4. CONCLUSION

The proposed new method of calculating the relative measure of industrial measurement system capability together with a proposal of combining it with PMAP method proves to have a lot of practical advantages. Its applying in the industry could be computer-aided and would make use of currently exploited statistical software.

Nevertheless, there is strong need for developing new universal procedures with an acceptable probability level of qualification errors as a basic criterion of acceptance of industrial measurement systems.

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