

METROLOGICAL CONFIRMATION OF THE INDUSTRIAL MEASUREMENT SYSTEMS

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Abstract - The main objective of the metrological confirmation of industrial measurement systems, which is a reduction of probability of products or production processes qualification errors, is presented. The evolution of the standardization guidance, including the latest editions of International Standards ISO 9000:2000 and ISO 10012:2003 is described. The question why the system of periodic calibrations is essential but not satisfactory procedure to obtain complete metrological confirmation is explained.

Introduction

Industrial measurement systems are used to evaluate products or production processes conformity with the requirements of technical specifications. These evaluations are based on the measurement results, which are the numerical projections (symbolic description) of the state of tested objects.

Such projections are imperfect because of deficiency of real measurement systems. As a consequence, incorrect measurement results may cause false evaluations of conformity, termed qualification errors.

In the industrial conditions, such errors result in technical and organizational difficulties, which may turn into heavy economical loss. As the qualification errors cannot be eliminated entirely, it is crucial for the producers at least to reduce the frequency of their occurrence to the acceptable level. This level should be determined by technological potential as well as economical limitations.

The complete project of the industrial measurement system should, therefore, consider not only a cost of measurement equipment but also costs of its implementation and exploitation as well as anticipated losses caused by wrong decisions, which are the consequence of possible measurement errors. In order to estimate this sort of losses, one should take into account: a capability of controlled production process, an adopted criterion of evaluation of product or production process conformity and, finally, an assumed acceptable level of probability of qualification error occurrence. The uncritical reducing of this level must result in the increase of metrological requirements and the need for more precise (thus more expensive) measurement equipment.

The cost of its exploitation - including periodical calibrations, monitoring and verification of system's metrological characteristics - will also be much higher. Thus, the choice of the ultimate solution should be a result of optimizing actions, which should include adopting the adequate technology of performing of measurement equipment.

The application of modern devices containing 'intelligent' elements and interfaces allow remote controlling the system and transferring measurement data between local networks and via Internet. It may undoubtedly raise the initial costs of purchase and implementation of the industrial measurement system. However, in the long-term perspective it should enable to use information technologies for elaborating and implementing a metrological supervision and verification system, based on 'artificial intelligence'. This solution would allow flexible optimization of time intervals between consecutive calibrations and obligatory verification actions, which in turn should result in substantial reduction of costs of exploitation of industrial measurement systems [1].

In author's opinion, present technological and standardizational conditions allow to create and develop the new generation of systems, which could be named: Computer Aided Metrological Confirmation Process (CAMCP). Such systems - in conditions of common use of computer networks together with 'business intelligence' conception of management - should enable remote supervising of

the industrial measurement systems, and also allow automatically recording and analyzing results of periodical confirmations (calibrations and verifications) in computer databases.

I. Evolution of Standardization Guidance

Programmers of the software for CAMCP systems should take into account the requirements of the latest standardization guidelines set in correlated standards ISO-9000:2000 and ISO 10012:2003.

The family of International Standards ISO 9000 regarding the quality management systems - and in particular their latest editions [2],[3],[4] based on the process approach - require from the producers to perform the processes of metrological confirmation of measurement systems, as these processes are necessary for right decision-making in organization management.

A general idea of the metrological confirmation process as well as detailed guidance regarding its implementation is described in separate standard ISO 10012. Its latest edition [5] is not only focused on the calibration procedures, but also stresses how important the process of verification of metrological characteristics of measurement systems is.

Results of such verification allow the operators of metrological confirmation processes to decide unequivocally whether or not a measurement system can be confirmed for specific intended use. Achieving and maintaining of this status is the fundamental condition of reducing qualification errors occurrence to the acceptable level.

The evolution of standardization guidelines - regarding both the quality management systems and the principles of management of measurement equipment in the industry - is an interesting example of rapid and thorough verification of standards, which has been the consequence of their practical application on very wide scale. The success of the first edition of ISO-9000 standards (thanks to their worldwide implementation) resulted in proposing to International Standard Organization a number of important amendments. Some of them, introduced in 2000, appeared to be very far-reaching. The good example of this evolution is radical redefinition of the fundamental term: **quality**. In Table 1. both previous and present definition are presented:

Table 1. The comparison of definitions of “quality”.

ISO-8402 : 1994	ISO-9000:2000
Quality: - totality of characteristics of entity that bear on its ability to satisfy stated and implied needs	Quality: - degree to which a set of inherent characteristic fulfils requirements

The above-presented juxtaposition shows that the new definition of ‘quality’ has completely diverted the way of reasoning and set the new course of necessary actions. According to this definition, the same product used by two customers with different requirements can indicate two different levels of quality. Referring this interdependence to the industrial measurement systems, one can say that a system with certain accuracy in one case can meet all requirements, but in another case - only a part of them.

The analysis of new standardization guidance [2], [3], [4] from the industrial measurement systems perspective allow to point at new terms that have been introduced in the standard ISO-9000:2000 (in the part regarding the assurance of measurement process quality - p. 3.10)

- measurement control system
- measurement process
- metrological confirmation**
- measuring equipment
- metrological characteristic
- metrological function

As none of these terms were defined in the previous version of standard ISO-8402, one can conclude that the sum of experiences aggregated in the industry during the implementation and application of the primary version of ISO-9000 standards have resulted in the growth of importance of quality assurance systems of measurement processes. It can be explained by the fact, that such systems allow managing the organization or production process based on “facts”, which means reliable evaluations basing on measurement results of due quality.

Described evolution of terminology has also affected two parts of standard ISO-10012-1:1992 and ISO-10012-2:1997, entitled as a whole: "*Quality assurance requirements for measuring*

equipment", and individually: *Part 1 - "Metrological confirmation system for measuring equipment"* *Part 2 - "Measurement assurance"*.

In the new version of standard ISO-10012:2003 [5], both parts has been put together into one standard entitled: *"Measurement management systems - requirements for measurement processes and measuring equipment"*.

In this case, not only a way of edition and the title of the standard have been changed, but also there have been essential modifications in the terminology. One of the most important is a different interpretation of term: **metrological confirmation**. In Table 2. two definitions of this term are presented:

Table 2. Two definitions of term: metrological confirmation.

ISO-10012-1:1992	ISO-10012:2003
<p>Metrological confirmation: set of operation required to ensure that an item of measuring equipment is in state of compliance with requirements for intended use.</p> <p><u>Note:</u> Metrological confirmation normally includes, inter alia, calibration, any necessary adjustment or repair and subsequent recalibration, as well as any required sealing and labeling.</p>	<p>Metrological confirmation: set of operation required to ensure that measuring equipment conforms to the requirements for its intended use.</p> <p><u>Note 1:</u> Metrological confirmation generally includes calibration and verification, any necessary adjustment or repair, and subsequent recalibration, comparison with the metrological requirements for the intended use of the equipment, as well as any required sealing and labeling.</p> <p><u>Note 2:</u> Metrological confirmation is not achieved until and unless the fitness of the measuring equipment for the intended use has been demonstrated and documented.</p>

Comparing above-presented definitions one can conclude that the new version of ISO-10012:2003 [5] standard substantially widens the process of metrological confirmation by adding very important function: verification. The objective of this procedure is to determine whether or not the identified metrological characteristics of evaluated measurement system meet the requirements set accordingly to the intended use of the system. Moreover, the results of such verification (as well as results of each calibration) should be properly documented and recorded.

II. Metrological Confirmation Process

After thorough analysis of the ISO 10012 standard, one can say that it is not an easy task to confirm the measurement system for the particular industrial purpose. A determination of basic metrological characteristics (trueness and precision) for the particular measurement system can be obtained through single, well-elaborated calibration procedure, applied under reference conditions.

However, more detailed analyses are required to determine complete metrological characteristics of measurement system performing a particular industrial work. All possible sources of variability of measurement results generated by the measurement system working in real conditions should be analyzed. Amongst various approaches, the most common is R&R (Repeatability and Reproducibility) analysis [5], [6], which, unfortunately, allows taking into consideration merely two sources of measurement results variability: the operator and the measurement equipment.

In order to examine the influence of other factors as well as to monitor time-related changes in metrological characteristics of the system, the PMAP method is recommended [8]. Contrary to R&R, this method also allows to control the bias of system's indications from the reference value.

Proposed combination of above-presented methods [9] seems to be a promising solution, although it requires practical confirmation in the industrial conditions.

A determination of metrological characteristics of the measurement system (trueness, precision, linearity, stability, uncertainty, etc.) working in real conditions (usually different from those in which the periodic calibrations are carried out) is just the one input of the metrological confirmation

process. The second input, which allows verifying these characteristics, are the metrological requirements determined by intended purpose that the system is to be applied for. In order to define these requirements correctly, one should at first consider the acceptable level of qualification errors occurrence, and then take into account the method of determining specification limits for products or production processes [9]. Moreover, a very important factor is the final purpose of performed measurements, i.e. determination of the process capability index, statistical control of the production output or monitoring of the process stability with Shewhart control charts.

The flow diagram of complete metrological confirmation process is presented on Fig. 1. It takes into account the guidelines included in the latest edition ISO-10012:2003 standard as well as author's proposal to combine two methods of determination of metrological characteristics of the industrial measurement systems [9].

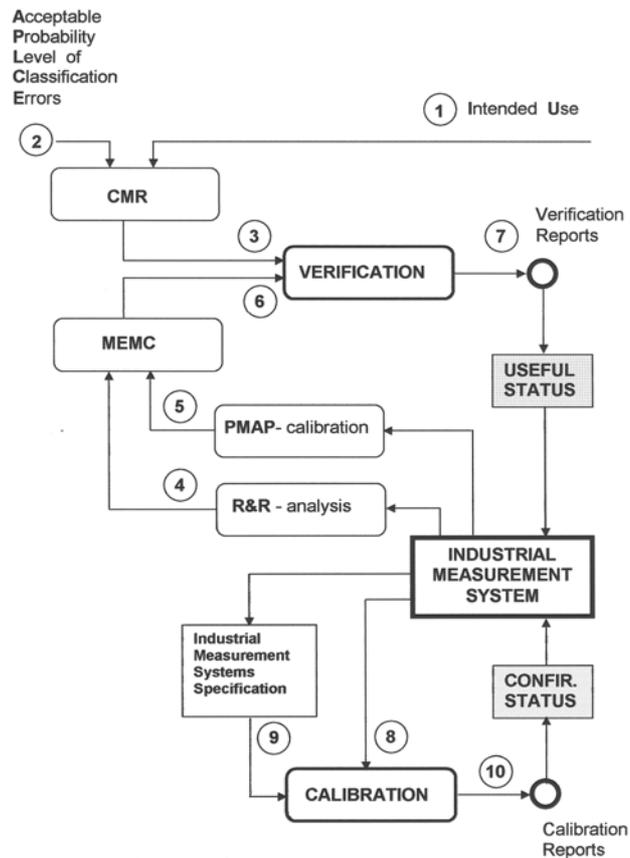


Fig.1. Flow diagram of the complete metrological confirmation process

Explanation of abbreviations:

CMR - Customer Metrological Requirements [5].

MEMC - Measuring Equipment Metrological Characteristic [5].

PMAP - Process Measurement Assurance Program [8].

A step-by-step description of the metrological confirmation process is presented in Table 3.

Table 3. Stages of metrological confirmations process

VERIFICATION PROCEDURE (obligatory)	
1	Determination of industrial measurement system's intended use (e.g. capability process evaluation, Shewhart control chart running, quality inspection of products, evaluation of conformity with tolerance zone, etc.)
2	Determination of acceptable probability level of qualification errors.
3	Analysis of data specified in stages 1 and 2 and determination of CMR - maximum permissible values of trueness $[\Delta^*_{\text{PERM}}]$ and precision $[s^*_{\text{PERM}}]$
4	Performance of R&R analysis and determination of experimental measure of precision $[s^*_i]$
5	Performance of system calibration by applying working standards in real environment and determination of experimental measure of trueness $[\Delta^*_i]$
6	Verification whether or not MEMC meets CMR requirements $[s^*_i < s^*_{\text{PERM}} \text{ and } \Delta^*_i < \Delta^*_{\text{PERM}}]$
7	Generation and documentation of verification report.
CALIBRATION PROCEDURE (if required)	
8	Calibration of the system in external laboratory of National Metrology Institute or in Accredited Calibration Laboratory.
9	Comparison of calibration results with IMS specification technical requirements.
10	Generation and documentation of calibration and confirmation reports.

Reports generated in stages 7 and 10 allow determining two kinds of status of industrial measurement system:

USEFULNESS STATUS - determining whether or not the system is capable for intended use.

CONFORMITY STATUS - determining whether or not metrological characteristics of the system meet requirements of Legal Metrology.

If the industrial measurement system achieves both of them, it is fully confirmed that it may be applied for intended use.

In the light of guidance of the ISO-10012:2003 standard and recently opened debate regarding calibration and verification procedures, one can say that the way of MEMC determining by two separate methods (proposed [5] and presented in Fig. 1) is satisfactorily justified and also particularly useful in the industrial practice.

The first of these methods - PMAP [8] - allow determining the experimental measure of trueness, which is the experimental bias:

$$\Delta^* = X_m - X_{\text{REF}} \quad (1)$$

where:

X_m - indication of evaluated measurement system

X_{REF} - reference value of working standard

Numerical values of trueness measures set in several checking points allow evaluating stability and linearity of the system as well as checking if each value Δ^*_i is smaller than maximum permissible bias Δ^*_{PERM} (which is the first criterion of CMR).

The second method - R&R analysis [7] - enables determining the experimental measure of precision:

$$s^* = \sigma_{R\&R} = \frac{(R \& R)_{0,99}}{5,15} \quad (2)$$

where:

Repeatability & Reproducibility

$$- (R \& R)_{0,99} = \sqrt{(EV)^2 + (AV)^2} \quad (3)$$

- EV - Equipment Variation (Measurement Equipment Variation in 99% range)

- AV - Appraiser Variation (Measurement Appraiser Variation in 99% range)

A numerical value of precision measure allows evaluating if each value $[s_i^*]$ is smaller than maximum permissible precision $[s_{PERM}^*]$ (which is one of the second criterion of CMR).

The additional advantage of this approach is possibility of replacing the R&R method by widely used methods of estimating the measurement uncertainty [U], which is also a measure of measurement system precision [13].

III. Conclusions

The general idea and respective stages of the complete metrological confirmation process of the industrial measurement systems are presented in this publication. It is proposed to determine MEMC by two separate methods, which allow determining the real measures of trueness and precision of evaluated system. It is proved that the verification process is the essential condition to obtain metrological confirmation of the industrial measurement system for intended use.

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