

COMPUTER AIDED METROLOGICAL CONFIRMATION PROCESSES - CAMCP

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Abstract: The need for undertaking the actions, aimed at elaborating the uniform methodology of carrying out the processes of metrological confirmation, was justified. The significance of the processes, which guarantee credible measurement results and the undertaking of appropriate decisions in the industrial quality management systems and systems of human safety management and health protection, was emphasized. Essence of adequate realization of the processes of metrological confirmation in respect to recommendations of international standards [1], [2] and the determination of two components of measuring system accuracy i.e. measures of precision and trueness, was described. Conception of the creation of the **CAMCP** computer system, supporting the realization of the processes of metrological confirmation in the present industrial conditions, was presented. This conception can be successfully used in other fields also.

Keywords: metrological confirmation, computer aided systems

1. INTRODUCTION

The Contemporary world is characterized among other things by still more complicated "techno-sphere" [3], that is the result of the fast development of advanced technologies enabling the creation of such complicated products as optical and mechatronic systems and various types of bio-systems.

Still more often, we observe difficult to forecast but characterized by catastrophic results phenomena occurring in the "eco-sphere". Tsunami, sudden downpours and windstorms cause the death of thousands people and an immense devastation of the natural environment.

So well considered and organized systems for the management of complex spheres of creative and manufacturing human activity and the environment of peoples lives, are really necessary. Such systems are created and subject to international standardization [1],[4],[5].

The target of such systems' operation is not only the assessment of the actual state of analyzed spheres but also forecasting the time at which the tested object will achieve the expected state. The next stage would be the prediction of

the moment when this state changes to the state that can be a danger to people's lives or not possible for acceptance.

In the case of these systems, it is also important to determine the causes of unwanted states. It enables the prevention, in adequate time, disasters or the costs of avoidable incorrect action.

Incorrect decisions undertaken in the Quality Management System is an example of such costs. The main reason for incorrect decisions, undertaken in the Quality Management Systems, is the inaccuracy of the measurements' results being the basis for the decisions undertaken.[6].

All the above facts together mean that there is a need for the elaboration of a uniform methodology increase still in the world. This methodology should enable the undertaking of unambiguous decisions if accuracy of the measuring system, measurements' results of which are the basis for the undertaken decisions, is enough to provide a great and possible acceptance probability of correct decisions.

Of course it is possible to strive all the time to increase the measuring systems' accuracy, but such an approach will prove difficult for acceptance of an increase of costs from the determined moment.

This costs' increase would be connected with the creation of a more accurate measuring system and its use including guaranteeing traceability with expensive standards which have very small uncertainty for the represented reference values

From the practical point of view, the procedure, aiming at the creation of the measuring system's accuracy [7] in such a way to as to provide credibility of the obtained measurements' results sufficient for the realization of intended use, with acceptable costs, would be the most reasonable.

The practice applied for many years in the industry for determination of Measurement Capability Indexes (**MCI**) [8], [9],[10] and approval of measurement systems is useful in the limited range only.

This is caused by the fact that the calculation method of Measurement Capability Indexes (**MCI**) takes into account, only one of accuracy components – measure of precision.

The situation connected with the actions aimed to determine the measurement results uncertainty is similar. These actions carried out with the use of even the most

complicated methods [11],[12],[13] provide in result only values of one of the accuracy components – value of precision measure.

Industrial experience proves that it is necessary to work out a modified and well agreed approach, which takes into account two components of the measuring system accuracy: measures of trueness and precision. The experiment described in paper [7] can be an example of the practical realization of such an approach and its positive results.

2. ESSENCE OF METROLOGICAL CONFIRMATION PROCESS.

The essence of metrological confirmation process has been agreed and is described in the international standard [2]. The character of this agreement is very general and can be presented in the form of diagram shown in fig. 1.



Fig. 1. Diagram of metrological confirmation process

CMR - Customer Metrological Requirements

MEMC - Measuring Equipment Metrological Characteristic

Standard [2] does not determine unequivocally how Customer Metrological Requirements (*CMR*) should be established. However it is emphasized in the standard that: **“The *CMR* should also take into account the risk of bad measurements, and the effects of these on the organization and the business.”**

In this standard [2] it was emphasized also that *MEMC* are determined most often in the calibration processes and calibration results should include an expression of the measurement's uncertainty.

However it was not mentioned unequivocally that during the processes of *CMR* and *MEMC* determination and next in the process of their comparison (see,fig.1), both components of the measuring system accuracy should be taken into account. These two components are measure of trueness and measure of precision.

The preliminary proposal for both accuracy components' consideration was presented in publication [15].

However in publication [7] it was stated that the practical realization of such an approach including also problem of calculation risk resulting from false measurements' results should be supported by computer system of *CAMCP* (*Computer Aided Metrological Confirmation Processes*)

Metrological confirmation processes that use such components of measuring system accuracy as trueness and precision, can be conducted in the situation when “historical data”, collected during periodically performed calibrations

of all measuring channels being components of the evaluated system, are accessible.

So, on the one hand, system of *CAMCP* type should enable the collection of *MEMC* (*Measuring Equipment Metrological Characteristics*)- in the computer data base. It concerns both characteristics declared by manufacturers of equipment and characteristics determined on the basis of “historical data” resulting from the previously performed calibrations of individual measuring channels.

On the other hand, this system should enable the determination of *CMR* (*Customer Metrological Requirements*), resulting from the intentional aim of measurements and taking into account an assumed allowable level of probability of the occurrence of false results of measurements.

The probability of occurrence of false results of measurements is determined first of all on the basis of acceptable negative economical, social and other effects, which can occur in the situation, when important but erroneous decisions would be taken on the basis of false results of measurements.

It is generally assumed that adequate evaluation of the uncertainty of the obtained results of measurements is sufficient for the evaluation of the probability of the occurrence of false results of measurements.

However, practice shows that the evaluation of uncertainty of the measurements' results, which is only a measure of precision, is sufficient for the evaluation of probability of qualification errors only in the situation, when decisions would be taken on the basis of measurements' results obtained after correction of systematic errors.

“Historical data” obtained during the calibration of individual measuring channels should create adequately associated pairs of measures of trueness and precision in order to enable such a correction.

Only such associated pairs characterize unequivocally metrological features of all individual channels being components of the evaluated measuring system. These associated pairs can be used as a basis for the indispensable correction of systematic errors and adequate evaluation of uncertainty of measurements' results with the use of very complicated methods [12], [13].

3. MEASURES OF TRUENESS AND PRECISION OF THE SINGLE MEASUREMENT CHANNEL

The simplest, direct measurement of a measured quantity of unknown X_0 value can be performed with the use of the single measurement channel that can be for example one of the ranges of hand-held digital multimeter, or one channel of a computer data acquisition board.

More complicated measurements require the application of several measurement channels of such metrological features which transform themselves into the final measurement result in accordance with the propagation laws determined in [11],[12],[13].

“Historical data”, collected during periodical calibrations of each individual measurement channel of system and being at disposal, are required in order to guarantee the possibility of the evaluation of the probability of occurrence

of false measurements' results in the measurement system consisting of several channels. This data enables first of all correction of systematic errors in each individual measurement channel and next, precision of system (as standard complex uncertainty) can be determined with using the recommendations given in [11],[12],[13].

Correction of systematic errors should be performed in each individual measurement channel with the use of the procedure that can be determined by the following general formula:

$$X_{m_MCh} = X_{bei_MCh} + C_{MCh} \pm U_{MCh} \quad (1)$$

where:

X_{m_MCh} - numerical value of measurements' result obtained in the individual measurement channel after correction of systematic error

X_{bei_MCh} - best estimation of indication of individual measurement channel. (average or median of values obtained as results of repeated measurements)

C_{MCh} - Correction, compensating systematic error, equal to the negative value of systematic error being measure of trueness of individual measurement channel

$$C_{MCh} = (-\Delta_{MCh}) \quad (2)$$

U_{MCh} - value of extended uncertainty – measure of precision of individual measurement channel.

Systematic error – ideal measure of trueness of individual measurement channel is defined in [14], as : a difference between average obtained from infinite number of repeated measurements $\bar{X}_{MCh_i\infty}$ of the same measured quantity of value – X_o , which can be expressed, as

$$\Delta_{MCh} = \bar{X}_{MCh_i\infty} - X_o \quad (3)$$

Extended uncertainty as an ideal measure of precision of individual measurement channel, determined on the basis of an infinite number of repeated measurements, can be expressed in the following way :

$$U_{MCh} = k_{MCh} \cdot u_{s_MCh} \quad (4)$$

where:

u_{s_MCh} - ideal standard uncertainty of individual measurement channel equal to the standard deviation σ_{MCh} which can be calculated as a square root of variance of an infinite number of repeated measurements' results.

$$u_{s_MCh} = \sigma_{MCh} = \sqrt{V(X_{MCh_i\infty})} \quad (5)$$

k_{MCh} - coverage factor responding to the accepted confidence

level and type of probability density function –pdf, that is recognized as a model of dispersion of an infinite number of repeated measurements' results performed with the use of the given measurement channel.

Graphical interpretation of ideal measures of trueness and precision of individual measurement channel is presented in figure 1.

One of the ideal measures of precision i.e. ideal **Measurement Channel Variation** - $MChV_\infty$ is presented in the figure also. $MChV_\infty$ can be expressed by the following formula :

$$MChV_\infty = 2 \cdot U_\infty = 2 \cdot k_{MCh} \cdot \sigma_{MCh} \quad (6)$$

This type of measure of precision defines the range, in which, the successive results of repeated measurements will get, with the probability responding to the assumed confidence level. This measure is used for the calculation of one of **MCI** (**Measurement Capability Indexes**) [8],[9], which can be used in the processes of metrological confirmation as **CMR** (**Customer Metrological Requirements**).

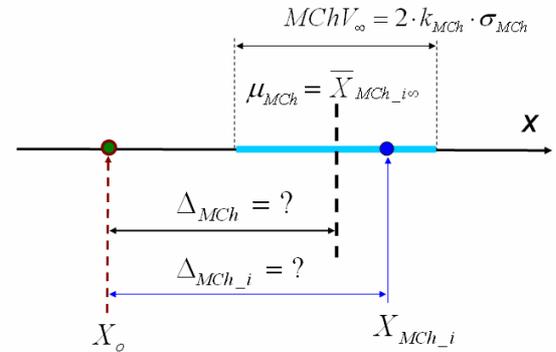


Fig. 1 Graphical interpretation of the ideal measures of trueness and precision of an individual measurement channel.

It should be noticed that direct determination of ideal measures of trueness (Δ_{MCh}) and precision (σ_{MCh}) is not possible, because value of measured quantity - X_o is unknown and an infinite number of repeated measurements cannot be performed.

So, in practice, numerical values of these ideal measures should be estimated on the basis of experimental measures of trueness and precision, determined during the processes of calibration in which measurements of **WS** (**Working**

Standard) or **RM** (**Reference Material**) representing reference value X_{REF} known with extended uncertainty U_{REF} , are carried out "n-times".

Graphical interpretation of experimental measures of trueness and precision being components of accuracy of individual measurement channel is presented in figure 2.

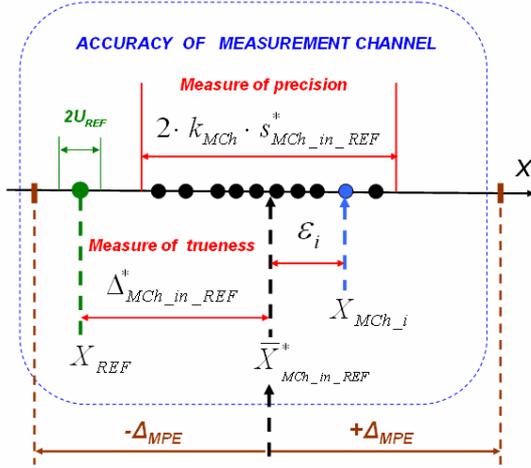


Fig. 2. Graphical interpretation of experimental measures of trueness and precision being components of accuracy of individual measurement channel.

Maximum Permissible Error Δ_{MPE} that can be calculated on the basis of declaration of manufacturer of measuring equipment included in the adequate technical specification, is presented in figure 2 also.

So, **Experimental measure of trueness of single measurement channel** is experimental bias calculated as a difference between average obtained from indications of single measurement channel $\bar{X}_{MCh_in_REF}^*$, determined on the basis of "n-time" repeated measurements of adequate working standard **WS** and reference value X_{REF} represented by this standard.

$$\Delta_{MCh_in_REF}^* = (\bar{X}_{MCh_in_REF}^* - X_{REF}) \quad (7)$$

So, **experimental measure of precision of single measurement channel** will be experimental standard deviation $S_{MCh_in_REF}^*$, calculated on the basis of repeated "n-times" measurements of adequate working standard **WS** representing reference value X_{REF} . Value of this experimental measure of precision which can also be treated as standard uncertainty [11], may be calculated with the use of the following formula:

$$S_{MCh_in_REF}^* = \sqrt{\frac{\sum_{i=1}^n (X_{MCh_i} - \bar{X}_{MCh_in_REF}^*)^2}{n-1}} \quad (8)$$

Considering expression (8), it can be determined unequivocally that knowledge of reference value X_{REF} is not necessary in order to calculate the experimental measure of precision. However it is worth to associate this measure with reference value X_{REF} that was measured.

Pairs of experimental measures of trueness and precision associated with given reference value :

$$\{ (\Delta_{MCh_in_REF}^*), (S_{MCh_in_REF}^*) \} \quad (9)$$

are basis for determination of MEMC (*Measuring Equipment Metrological Characteristics*) indispensable for the correct performance of metrological confirmations' processes.

One should remember that numerical values of each of these measures, creating pairs associated with given reference value X_{REF} , are most often different for other reference values. Therefore, it is extremely important to create and run a computer data base in order to accumulate historical data collected during the periodical calibrations of individual measurement channels, at least in three points of calibration.

Data of such a type enable the execution of necessary correction of systematic errors for individual measurement channels and guarantee correct evaluation of complex uncertainty for the whole measurement system. This data also enable the use of adequate Shewhart control charts monitoring **MEMC** stability and determination of well-grounded time intervals between successive calibrations.

4. DESIGNING & DEVELOPMENT OF THE CAMCP SYSTEM

The **CAMCP** system can be created as a system destined for one organization or as a fragment of greater regional, national or international consulting and education systems similar to the systems described in [17], [18], [19].

In starting the design of **CAMCP** type, its destination should be determined at first. Next, adequate separation of intended applications should be carried out. Such a separation should take into account first of all the fields where these measurements are to be performed (physical measurements, chemical measurements and other...).

In each of these fields the intended application of the performed measurements should be determined. Examples: determination of production processes capability indexes (C_p), assessment of products' compatibility with specified requirements (*specification limits* – **LSL**, **USL**), usage of Shewhart control charts or carried out optimizations of machine set-ups with **DOE** methods used.

It is necessary to establish basic requirements for each of the intended applications of measuring system: **permissible value of probability of making qualification errors**

(so acceptable value of probability of incorrect decision undertaking).

On this basis, the *CAMCP* system, with the possibility of the use of adequate statistical analysis procedures, should enable the determination of acceptable values of trueness and precision measures establishing adequate *CMR* formulation.

Adequate formulation means such a formulation that enables comparison of *CMR* and *MEMC* and the determination of usefulness status for the measuring system that is to be used for the realization of intended use.

In order to provide adequate *MEMC* determination, *CAMP* system should be equipped with procedures enabling the analysis of calibration results, the forecast of time-limits for their next realizations and assessment of stability of trueness and precision measures establishing adequate *MEMC* determination.

5. PROTOTYPE VERSION OF CAMCP SYSTEM

The prototype version of the *CAMCP* system has been designed and started up, taking into account principles of creation and development of such systems, described in chapter 4. Available, recommended [16] and free of charge Information Technology has been used for the creation of this system version.

Necessary data base was created in the environment of "mySQL" type. Whereas, interactive website "www" enabling access to the data accumulated in the data base and their supplementing and modification were done with use of "PHP" technology. Interactive home page of prototype version of *CAMCP* system is presented in figure 4.



Fig. 4. Interactive "www" home page of the prototype version of the *CAMCP* system

The main modules of the *CAMCP* system are visible on the left side. They are accessible only for the authorized customer, who may "login" by entering an adequate password. After login, an authorized customer can use all *CAMP* system's modules, main functions of which are specified in Table 1.

Supplementing modules, accessible on the Internet 24 hours a day, are visible in the upper part of interactive "www" website, shown in figure 4. They guarantee the achievement of new information on activities of laboratory

developing and making accessible, the potential possibilities of the *CAMCP* system. Obtaining the information materials and software, free of charge, is also possible. Interested persons may make contact with specialists managing and improving *CAMCP* system.

Table.1. Basic functions of the main modules of the *CAMCP* system

Name of main module	Basic functions
MEASUREMENT EQUIPMENT SPECIFICATIONS	Introduction of data from the technical specification of measurement equipment having one or more measurement channels.
MEASUREMENT CHANNELS CHARACTERISTICS	Accumulation of data of metrological features of single measurement channels and their grouping depending on the type of measured quantity and useful measuring ranges
HISTORICAL DATA OF CALIBRATIONS	Accumulation of data collected during periodically performed calibrations of single measurement channels and making them accessible for the analysis
COLLECTION OF INTENDED APPLICATIONS	Accumulation of data enabling the determination of Customer Metrological Requirements <i>CMR</i> , taking into account an assumed allowable level of probability of occurrence of false results of measurements
MEASUREMENT SYSTEMS CREATION	Creation of measurement system consisting of single measurement channels of known historical data collected during periodical calibrations and accumulated in data base.
MEASUREMENT SYSTEMS CONFIRMATION	Determination of <i>MEMC</i> on the basis of the metrological characteristics of individual measurement channels. Verification, if <i>MEMC</i> meets requirements of <i>CMR</i> and generation of status of metrological confirmation.

Prototype version of the *CAMCP* system is tested with the use of the information infrastructure of *Rzeszów University of Technology*, created, managed and developed by *Testing & Calibration Laboratory of the Department of Metrology and Measurements Systems*.

Diagram of the information infrastructure, in which the prototype version of the *CAMCP* system is tested, is presented in figure 6. System of this version is designed first of all for the processes of metrological confirmation of digital multimeters of a resolution not higher than 4 1/2.

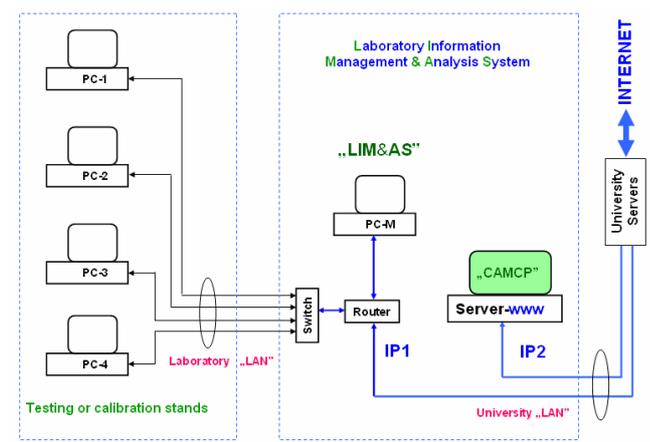


Fig.6. Diagram of information infrastructure, in which prototype version of the CAMCP system is tested.

Testing of prototype version of the *CAMCP* system, carried out with use of Laboratory Information Management and Analysis System – *LIM&AS* is visible on figure 6. This system connects itself with the *CAMCP* system and makes use of its capabilities through an interactive “www” Website. It is done exactly in the same way, as it would be done by an external customer.

4. SUMMARY

The need for the creation of systems of the *CAMCP* type is justified in this publication.

These systems can be used in systems for measurements supervision recommended by standard [1] or in consulting and education centers described in [17], [18], [19], which apply education technology in the scope of industrial metrology with the use of Internet possibilities (*e-Learning*).

Principles of creation of the *CAMCP* type systems were described and an example of one of their prototype realizations was presented.

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