Uncertainty As The Component Of The Measurement Result In Microprocessor Instruments

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Abstract - A traditional description of the measurement result obtained with the use of a definite measurement instrument is complemented by the information about its accuracy on the basis of technical specifications given by its producer or verified in checking and legalisation procedures. The paper presents the premises resulting from currently available technical possibilities, which show that it is purposeful to complement the set of functions realised in a microprocessor instrument with additional properties enabling the instrument user to access the information about the uncertainty of the measurement result. The configuration of the measurement instrument, which enables an access, apart from the measurement result, to the information about the uncertainty as the component of the result, is presented. The conditions referring to the set and programme configuration of the instrument, indispensable for the realisation of the proposed idea, are pointed out. The main ideas of the presented paper will be also found in the authors' work [9].

I. Introduction

On the basis of metrological knowledge available, a measurement instrument operator uses among others the accuracy data of the instrument in order to determine the uncertainty of the obtained measurement results. In practice, very often only the data given on the instrument (lost technical documentation) is used or the accuracy analysis of the result (e.g. in relation to the belief in the accuracy of digital instruments associated with the number of displayed digits) is neglected. A separate problem is the use of measurement instruments in the conditions that do not conform with the operating conditions given by the producer.

The user of the measurement instrument does not have the information about the course and the detailed results of instrument examinations in the stage of its development or legalisation. On the basis of the information about the accuracy class, first the value of the basic error Δ_{basic} is designated, and then the additional errors Δ_{add}. Taking into account the procedure of instrument calibration and the method to determine its class according to recommendations contained in [3,5] and assuming the uniform distribution of uncertainty, it is possible to determine the standard uncertainty u.

Figure 1 presents the algorithm to determine the measurement uncertainty on the basis of its accuracy data (*B-type* uncertainty). In relation to traditional analogous or digital instruments the instrument user carries out the accuracy analysis usually "manually" regardless of the type of the instrument.

It is recommended in [3] that the accuracy information in the form of the expanded uncertainty U corresponding to the *level of confidences* amounting up to about 95% with the use of the expansion coefficient $k=2$, should be given.

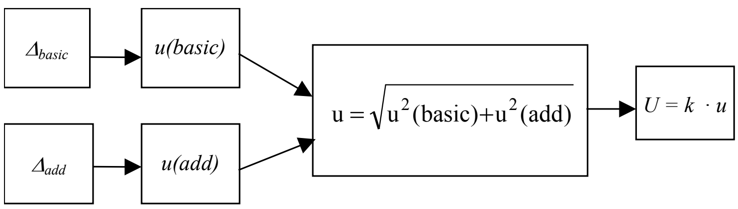

Figure 1. Exemplary algorithm to determine the standard uncertainty by the measurement instrument user

The user of the analogous instrument has usually an easy access to the information about the class of an instrument placed directly on the scale plate. The situation gets complicated with digital instruments, where the problem of the access to technical documentation of the instrument occurs (also losing technical data). The measurement instruments are sometimes used out of their usable condition range, where a producer doesn't denominate its accuracy features.

A more spread use of microprocessor technique to build various measurement instruments allows realising many additional functions besides the basic measurement functions of a given type instrument. There is a wider range of adaptation properties [1] connected with the change of specific parameters in reference to the measurement conditions, which are built up in these instruments.

Such technology makes it also possible to build in into the software of an instrument the algorithms for the assessment of the measurement result uncertainty and to make available to the user the value of uncertainty as the supplement to the result. It can be especially useful with multifunctional instruments, where for each measurement function the assessment of uncertainty requires a separate approach. It is possible then to use two different ways of solving the problem of determining and making available the information about the measurement uncertainty:

- *passive* – the use of algorithms following the obligatory procedures realised by the user; the uncertainty of the result is determined according to the use of the measurement function of the instrument,
- *active* – the use of the appropriate standards and sets of autocalibration of the measurement channels; in such a situation some procedures connected with the standardisation of the instrument would be moved from a legalisation laboratory to the instrument. In the laboratory only the standards used in the instrument would be checked (e.g.: standard sources u_{ref}, i_{ref}). The results of checking would be stored in the form of the appropriate parameters in the instrument memory.

The first method has some advantages: the user does not have to think about the problem of documentation availability and the necessity to carry out some calculations. The output data for the analysis in the algorithms of the instrument is the information about the accuracy class obtained traditionally, as the result of legalisation examinations. Such a solution does not bring new elements to the assessment of the result uncertainty; it only makes it easier to access some specific information. Natural changes in the characteristics of procession are not reflected in the available to the user information about the accuracy. The instrument must periodically undergo standard legislation procedures. Their results (e.g.: in the form of the *class* or directly the uncertainty values) must be entered to the instrument memory and are made use of in determining the uncertainty value for particular measurement functions according to the algorithm presented in Figure 1.

Th*e active* approach taken to solve the problem makes it possible to obtain the accuracy information resulting from the current conditions of the measurement. The result uncertainty for a chosen measurement function is determined with the use of additional procedures including the measurement of the property of the measurement channel by using additional sources of the standard signals.

Within the examinations carried out, an attempt was made to implement the assumptions constituting the other from of the mentioned solutions of determining and making available the information about the result uncertainty.

II. Checking the measurement instrument

One of the basic properties of the instrument is its measurement range, that is the range of the measured value, for which the instrument indications meet the accuracy requirements. In result, the legislation procedure of an instrument should give an answer to the question: what uncertainty does the measurement result with the use of the instrument in any point in the measurement range bear? Checking should be carried out in the justified number of the points within the range. The checking results in the traditional form of a protocol are used in practice, when they involve confirming the *class* of the instrument defined by the producer or awarding this class with the new value. The tabular data containing the checking results in chosen points of the measurement range are used sporadically in the exploitation practice.

III. The configuration of the microprocessor measurement channel

By applying of the microprocessor technology to the measurement purposes the software becomes the part of the measurement channel [7]. This fact enables applying to measurement instrumentation many additional tasks, next to the main measurement functions. This possibility is owing to the big flexibility of software.

To design of uncertainty designation procedure it is necessary to take account of few factors, i.e.:

- supplying of the measurement channel with appropriate pattern sources for calibration needs,
- applying of the adequate software algorithms for a designation of the components of the random and systematic effects,
- working out of algorithm of adaptive correction of measurement result,
- elaborating of the uncertainty budget concerning to whole measurement channel, alike to its analog and digital part and appropriate algorithms.

The exemplary block diagram of the procedure of the measurement uncertainty designation is shown in Figure 2.

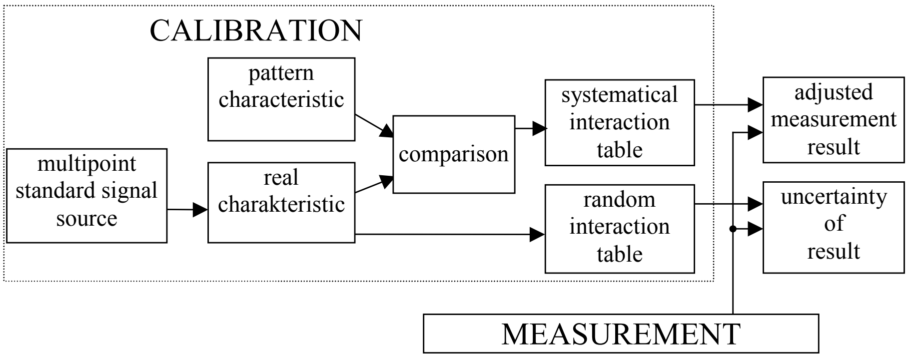

Figure 2. The procedure of the adaptive designating of the measurement result

The measurement channel of a multifunctional microprocessor instrument, on whose input analogous measurement signals are given, is presented in Figure 3. As far as the set is concerned, it is possible to distinguish: the analogous part realising the conditioning of the measurement signals, A/D converter and the digital part – the microprocessor set which ensures the realisation of the algorithms resulting from the measurement functions of the instrument [7,8].

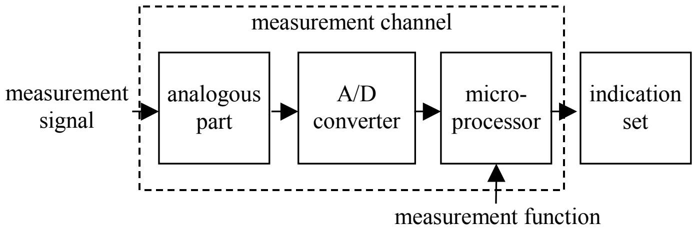

Figure 3. Exemplary structure of the measurement channel of the microprocessor instrument

The measurement results obtained form the indication set of a given instrument are made use of generally in the form of one reading of indications, possibly in combination with the observation of their stability. For the assessment of the accuracy of such results only the method of *B-type* of uncertainty measurement can be used. Taking into account the *passive* approach to the problem of information availability, it is possible to enter to the instrument memory the checking results obtained in the points within the range (there is a necessity to design the appropriate mechanisms of introducing such data). On this basis, simple software algorithms allow determining the uncertainty in any range point and giving it to the user together with the measurement result. For the multifunctional instrument the algorithm to determine the result uncertainty results form the realised measurement function.

Taking the *active* approach to the problem and taking into account the usefulness for further considerations, the structure of the multifunctional instrument measurement channel can be presented in the form as presented in Figure 4.

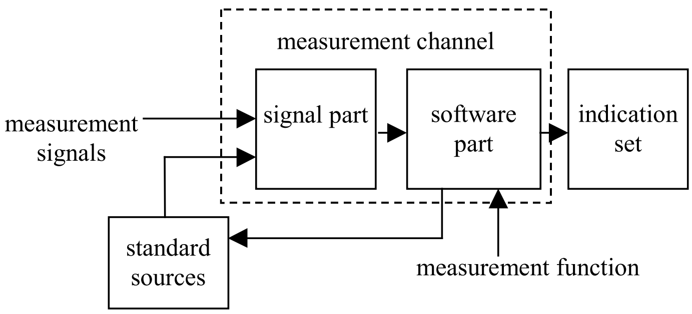

Figure 4. Components of the measurement channel of the microprocessor instrument related to *active* approach

The way to distinguish functional blocks results from the proposed approach to determine the measurement result uncertainty. On the input of the measurement channel the voltage changing linearly in a given standard range of values, for instance: $0...U_{ref}$ is given (Figure 5). Simultaneously, with the appropriate distribution t_r, the time axis for the changes in this voltage is reproduced as foreseen in the software. The signal part (data acquisition) of the measurement channel contains the analogous sets of measurement signal conditioning (including: input circuits, separation sets, sets

normalising the signal) and the analogous-digital converter (together with the S/H set). The output data, in the form of digital words, undergoes processing in the software part (data estimation) of the measurement channel according to the algorithm corresponding to a chosen measurement function.
The procedure to determine the result uncertainty contains two components:

- examination (identification) of the properties of the signal part of the measurement channel with the use of the signal from the reference source
- determination of the value of the uncertainty brought in by the software part of the measurement channel

The linearly increasing voltage $u_w(t)$ (Figure 5) from the standard source reaches the value U_{ref} after time t_w. The voltage, having been elaborated in the conditioning sets, is processed in the converter A/D. The distribution t_r of the time axis reproduced with the use of a microprocessor, the sampling step ι of the converter and the time t_r of the voltage growth $u_w(t)$ remain in the interrelation described by the dependence (1) (Figure 6).

$$t_r << \iota << t_w \tag{1}$$

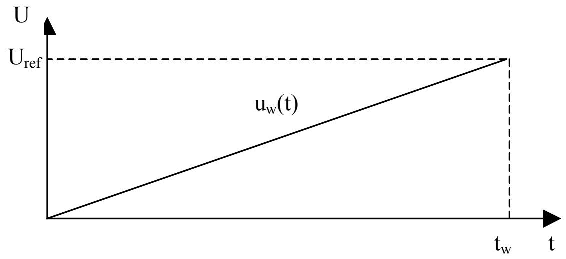

Figure 5. Standard voltage characteristics

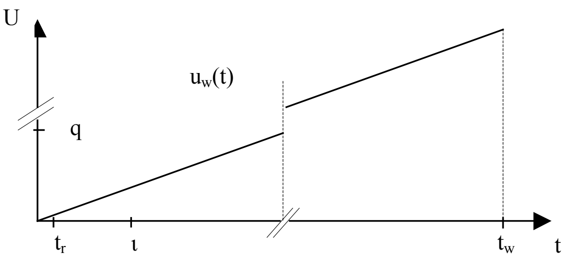

Figure 6. Relation standard voltage characteristics

On the basis of the set of the registered processing results $\{Y_i\}$, the real characteristics y(x) of the signal part of the measurement channel (2) is estimated with the use of the method of linear regression [2,6].

$$y(x)=ax+b \tag{2}$$

For the A/D converter of N-number of bits in the output word, the digital representation of this characteristics is a set consisting of $n=2^N$ elements, and the element Y_k corresponds to the input voltage of the converter (3).

$$y_k=kq \tag{3}$$

where: q – the value of converter quantum, y – the value of the input signal of the converter A/D assigned as a result of digitisation to the range (y_k-q/2, y_k+q/2) (Figure 7).

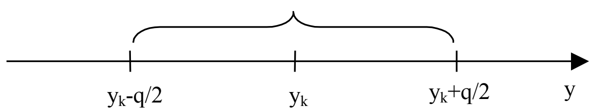

Figure 7. Digitisation of the signal level

The range ±q/2 is determined for the point Y_k on the measured real characteristics with the use of a time constant t_r. In this range there are values Y_{i_k} obtained while checking the signal part of the measured channel. Similarly, for the complex ideal characteristics of the measured channel $y'(x)$ (4), it is possible to determine for a singular measurement the digital value of the correction (5) in the *p* point of the characteristics.

$$y'(x)=a'x+b' \tag{4}$$

$$\Delta_p=Y_p-Y'_p \tag{5}$$

The dispersion of the checking results of the signal part of the measurement channel can be used to assess the uncertainty in three ways:

- determining the maximal value of the deviation Δ_1 of the appropriate checking results from the points Y_k of the estimated real characteristics in the whole range of procession for all n levels of quantisation

$$\Delta_1 = \max\{|Y_k - Y_{i_k}|\} \tag{6}$$

  The obtained in this way boundary deviation (uniform distribution) can be used to assess the standard uncertainty

- determining the quadratic mean deviation of the arithmetic mean σ_2 (normal distribution) of the appropriate checking results from points Y_k of the estimated real characteristics using the dependence (7)

$$\sigma_2 = \sqrt{\frac{1}{m\cdot(m-1)}\sum_k^K\sum_{i_k}^{I_k}(Y_k - Y_{i_k})^2} \tag{7}$$

  where:

$$m = \sum_k I_k \tag{8}$$

- determining the quadratic mean deviation of the arithmetic mean σ_3 (normal distribution) of the appropriate checking results around the point Y_{i_k} of the estimated real characteristics for the singular measurement Y_p using the dependence (9)

$$\sigma_3 = \sqrt{\frac{1}{I_k(I_k-1)}\sum_{i_k}^{I_k}(Y_k - Y_{i_k})^2} \tag{9}$$

For each of the above procedures the standard behaviour is applied which leads to the determination of the standard certainty *u* and the expanded uncertainty *U*.
The result uncertainty brought in by the software part of the measurement channel can be determined for the realised measurement function by the algorithms analysis taking into account the precision of the processed data and the applied roundings in the numeric operations [2,4].

IV. Preliminary conclusions

It appears, there is possible to implement to microprocessor instrument tasks the designation of the measurement uncertainty, instead to put this procedure on the user duties.

For the realised measurement channel, the uncertainty budget contains the components resulting from the properties of the input circuits not included in the procedure of checking the measurement channel, the results of determining the uncertainty of the signal and software part, and also the component connected with the resolution of the indication set.

With the use of the appropriate sets of reference signals and autocalibration techniques, the determined and given value of the uncertainty takes into account the current conditions of the instrument functioning. As a result, it is possible to elaborate the adaptation measurement algorithms of the instrument, which take into account the influence of the systems and random interaction on the parameters of the measurement channel. It is possible to correct the result taking into account the real characteristics of the measured channel as well as the determination and indication of the uncertainty accompanying the results. The subject of the carried out research is the verification of the proposed procedures of determining the uncertainty and the analysis of the obtained results in comparison to the results obtained with the use of the traditional approach.

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