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Software for data acquisition with options for multimeter calibration and verification of its accuracy

Abstract

The need to create software for measuring data acquisition to ensure data collection during calibration of the multimeter and to verify its accuracy was justified. The prototype of such software working with the M-4650CR multimeter was developed in the VBA MS Excel environment. This software, called "CAL-DAQ", is a modular structure that enables the execution of individual modules in order to facilitate the measurement procedure. Software of this kind can be useful in industrial measurement management systems which are an important part of quality management systems.

Keywords: data acquisition, calibration, accuracy verification, measurements management systems.

1. Introduction

Industrial measurement management systems [1] constitute an important part of the quality management systems [2]. They should provide in the industry applying only such measurement processes, which comply with the metrological requirements of the intended use of measurement results. The primary metrological requirement, which should meet the supervised measurement process, is that obtained results must have a specified accuracy expressed in the form of acceptable numerical values of correctness and precision measurements.

The accuracy of measurement results depends on many factors [3], which can change over time. For this reason periodic calibration is necessary. The correctness and precision of current measurements have to be kept.

A numeric measure of the correctness is a value of systematic error, while the numerical measure of precision is among others doubled value of extended uncertainty. Doubled value of extended uncertainty, called variability of measurement process (VMP) [5], is a spread of value interval representing the final measurement results (1).

The numerical VMP value is used to calculate the capacity rate of the measurement process C_{g2} .

This index is used for the validation of the measurement process which is applied to the quality assessment of production processes. However, validation is an experimental confirmation of the fact that metrological properties of the evaluated measurement process complies with the requirements of the intended use of measurement results [4], [5]

Development and validation experimentation is not a simple issue and requires the use of appropriate equipment and implementation of appropriate actions in a predictable order [4].

In practice, it consists of the selection and application of an appropriate set of sources of the reference values, such as working standards and the use of a fixed validation procedure at the place of application of the evaluated measurement process [5].

There are two types of software which are helpful in implementation of the full validation procedure [4], [5], including the development of obtained results and generating the final report. One type is software that enables the collection of periodic calibrations in the metrological database [6]. The second type is software that controls the calibration process and analysis of the results obtained in this process. This analysis is conducted in order to verify the accuracy of periodically calibrated measurement equipment.

Design assumptions adopted to develop the prototype of the second type of software, its description and test results are presented in this publication.

2. Assumptions for the software project

The second type of software, meeting the above mentioned requirements, should consist of two modules. The first module should enable the determination of the corrective function and verification of the reading's accuracy in order to check whether this reading's accuracy is consistent with the accuracy declared by the manufacturer of the assessed measuring equipment. The second module should enable the acquisition of measurement data, taking into account the correction of systematic errors and expressing the final measurement results in a form of value intervals, whose spread is a measure of the dispersion of measurement results.

From the metrological point of view, the most important aspect is that the measurement results must be expressed in the form of an interval:

$$X_m = [x_l, x_u], \quad (1)$$

including real value x_o of measured size, represented in practice by known reference value x_{ref} with very small uncertainty.

$$x_o = x_{ref} \in [x_l, x_u], \quad (2)$$

Fulfillment of the condition (2) as the main purpose of every measurement is only possible when the measuring procedure includes the correction of systematic errors and implements the appropriate convention of expressing the final measurement result.

Various approaches to the convention of expressing the result of measurements can be found in the literature [5], [7], [8], [9], [10].

2.1. Convention of expressing measurement results

Creating software for measuring data acquisition, equipped with the module of expressing the final measurement result and verification of its accuracy, it is necessary to adopt a clearly defined convention of expressing this result.

The measurement result, in industrial conditions, is often a single value read out from the reading field or memory of the measuring instrument, or a value of average values read out from "n-times" repeated measurements. In view of this, and in order to ensure the expression of the final measurement results in a form of intervals (1) meeting the conditions (2), it was assumed that the ends of the ranges constituting the final measurement result would be calculated in the following way:

$$x_l = x_{ml} - U, \quad (3)$$

$$x_u = x_{ml} + U, \quad (4)$$

where: x_{ml} – a measure of location of read values (x_{rdg})

U – expanded uncertainty as a measure of dispersion

x_l – the lower end of the values range

x_u – the upper end of the values range

If the location measure of the value of readings x_{rdg-i} , without applying the correction of systematic errors, is an average value from "n-times" repeated measurements of the same value of measured size, then its numerical value is calculated in the following expression:

$$X_{ml} = \sum_{i=0}^n X_{rdg-i}, \quad (5)$$

In the case of carrying out individual measurements, with a position measure of read value without correction of systematic errors, there is an individual reading indication:

$$X_{ml-i} = X_{rdg-i}, \quad (6)$$

The dispersion measure of read values, irrespective of whether a correction of systematic errors was conducted, is extended uncertainty U , which according to [7] can be estimated by type A method, using statistically calculated results from a series “ n -times” of repeated measurements. In this case, extended uncertainty should be expressed as:

$$U = k_p \cdot u_s, \quad (7)$$

where: u_s – standard uncertainty (standard deviation)

k_p – extension rate for accepted confidence level p .

According to [7], expanded uncertainty U can be estimated by various approaches to the convention of expressing the result of measurements, which can be found in the literature. The uncertainty estimated by the B method for the measurement result being a single reading from the measuring instrument, can be expressed as:

$$U = |MPE|, \quad (8)$$

where: MPE – Maximum Permissible Error.

Type B method is used in practice very often to estimate the uncertainty of individual measurements carried out with electronic multimeters or computer data acquisition cards.

If a raw measurement result obtained by the multimeter is used in indirect measurement, as an input value entered into the equation, then the standard uncertainty needed to be taken into account in the budget of uncertainty is estimated using the expression:

$$u_s^B = \frac{|MPE|}{\sqrt{3}}, \quad (9)$$

This results from the adoption of a uniform distribution as a model describing our information about the location of individual values in the range.

The application of the type B method presented above, to estimate the uncertainty of measurement results obtained using electronic multimeters, provides good results if MPE errors are properly calculated for each location measurement of read values x_{ml} .

2.2. Maximum Permissible Errors – MPE

Software for measuring data acquisition with an option to verify the accuracy of the multimeter’s indication, due to accuracy declared by their producers, should properly carry out calculation of the value of Maximum Permissible Errors MPE .

MPE values for electronic multimeters are different for each determined location measure of read value x_{ml} . For this reason, this type of software should enable the entering the values of indicators, relevant for the given measuring scope, before starting the calibration process.

Producers of multimeters, using the data collected in calibration production, provide the indicator values (a , b , c , d) in specifications, which enable the calculation of the numerical value of permissible maximum errors MPE . However, they do not provide the equation to calculate MPE . Therefore, it is important to use appropriate mathematical expressions in calculations [11].

One of checked variants to calculate MPE is the expression:

$$|MPE| = a \cdot \frac{|x_{ml}|}{100} + b \cdot \frac{|X_N|}{100}, \quad (10)$$

A second variant is the expression:

$$|MPE| = a \cdot \frac{|x_{ml}|}{100} + c \cdot d, \quad (11)$$

Selection of one of above described variants depends on which indicator is provided by the producer in specifications. Individual indicators, identified by the letters a , b , c , d , [11], provided by producers of multimeters have the following meanings:

- a – part or multiple of one percentage of the indicated value
- b – part or multiple of one percentage of the value of used measuring range (X_N)
- c – multiple differentiation of read field
- d – differentiation of read field

Analyzing the expressions (10) and (11), it is easy to notice that two parts make the MPE value. One part is dependent on the value of position measure of read value and increases along with its growth. Let us call this error the multiplicative permissible error (PE_{mul}). The second part is independent on indicate value and it is possible to call it the additive permissible error (PE_{add}). Therefore, it is possible to express it in a form of:

$$|MPE| = |PE_{mul}| + |PE_{add}|, \quad (12)$$

2.3. Accuracy verification of the multimeter indications

Accuracy verification of the multimeter indications can be conducted in terms of various criteria. One of the basic criteria is the assessment of accuracy with regard to the declared accuracy by the manufacturers. A multimeter, whose accuracy at the given measuring range is not worse than the declared accuracy by the manufacturer, should for each indication in this regard meet the following condition:

$$|Bias| + U \leq |MPE|, \quad (13)$$

where:

$$Bias = x_{ml} - x_{ref}, \quad (14)$$

The software should enable automatic performance of graphical representation of the function:

$$Bias = f(X_{ml}), \quad (15)$$

on the background of Permissible Maximum Error limits. Such a graphical representation enables quick verification of the condition (13) and accuracy for the multimeter due to the accuracy declared by its manufacturer.

Since the delta deviation is an approximate value of instrumental systematic error Δ_{si} ,

$$\Delta_{si} \approx Bias, \quad (16)$$

it can be used for determination of corrective function:

$$C = f(X_{ml}), \quad (17)$$

where:

$$C = -Bias, \quad (18)$$

With the mathematical figure of the corrective function, appointed for the given measuring range for the multimeter, it is possible to express measurement results taking into account the correction of systematic errors and using corrected values X_c .

$$X_c = X_{ml} + C, \quad (19)$$

The final result of conducted measurements by the multimeter, after correction of systematic errors will have a form of interval (1), whose ends will be calculated using the following expressions:

$$x_l = x_p - |MPE|, \quad (20)$$

$$x_u = x_p + |MPE|, \quad (21)$$

Determined in this way, the corrected measurement result has a very great probability of including the real value X_0 of the final measurement result (1).

In practice, a known reference value X_{ref} with negligible uncertainty is set to a good quality calibration. However, the major problem is that for each position measurement of read value X_{mpo} , the value of MPE is different.

Conducted long-term studies have shown [11] that application of the correction of systematic errors, on the basis of the earlier appointed corrective function, enables the expression of the final measurement result in the form of an interval, whose ends can be calculated using the following expressions:

$$x_l = x_c - |PE_{add}|, \quad (22)$$

$$x_u = x_c + |PE_{add}|, \quad (23)$$

In this case, the additive component PE_{add} (12) is a constant value in the entire measurement range and can be accepted as the value of extended uncertainty. In such a situation, the value of uncertainty is estimated in this way, and it is at least two or three times smaller than the value of uncertainty estimated using MPE (8). This has a special importance when the measurement result obtained by the multimeter is used in indirect measurement and is used as the input value entered into the equation. Standard uncertainty of such a measurement result needed to be taken into account in the budget of uncertainty, it is then possible to be estimated using the type B method, using the expression:

$$u_s^B = \frac{|PE_{add}|}{\sqrt{3}}, \quad (24)$$

Verification of the possibility of using the expression (24) should periodically be conducted for each used measurement range of the multimeter. Implementation of this verification should be conducted by a software module designed for data acquisition, which carries out correction of instrumental systematic errors, based on the previously designated correction function (17).

3. „CAL-DAQ” Software

For experimental verification of the correctness of the assumptions presented in Chapter 2, the “CAL-DAQ” software was developed in the VBA MS Excel environment [13]. This software consists of two modules. One module is titled “CALIBRATOR”, and the second “ACQUIRER”.

The “CALIBRATOR” module enables the conduction of calibration of the multimeter and appoints the corrective function (16). With this module it is also possible to automatically draft the graph of delta deviations in the function of location measure of read value (14) marked on the MPE limits. This provides the possibility of a fast verification of the multimeter accuracy in terms of declared accuracy by its producer.

The “ACQUIRER” module enables the acquisition of measurement data, without correction and with correction of systematic errors. This module also enables verification of the

accuracy of readings due to the possibility of using the expression (24) for estimating the standard uncertainty.

The launched prototype software is designed to be used with the M-4650CR type handheld multimeter. However, by adopting the same assumptions presented in Chapter 2, it is possible to develop software in a different environment, which performs the same functions, but can work with other types of multimeters.

Such software can also be expanded and equipped with additional modules that enable manually entering read values x_{rdg} . Such an option would be very useful for calibration of multimeters with no interface to transfer the measurement results to PC.

Figure 1 presents “START SCREEN” of the “CAL-DAQ” software.

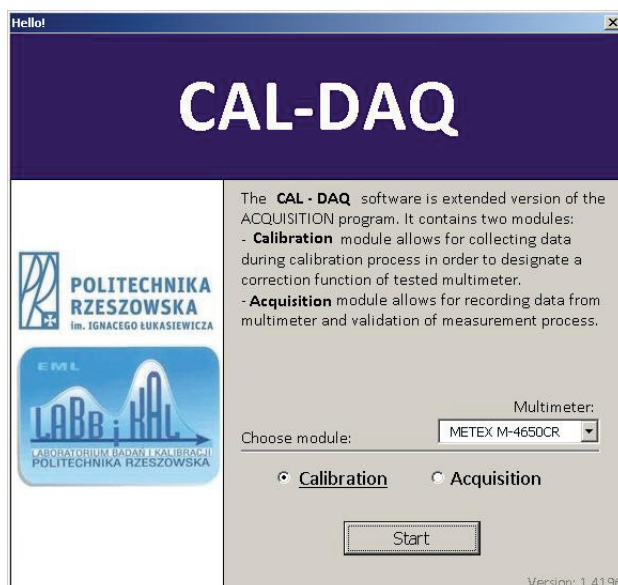


Fig. 1. “START SCREEN” of “CAL-DAQ” software

Presented in Figure 1 “START SCREEN” enables the selection of one of two modules. “CALIBRATOR” module is selected for calibration, and “ACQUIRER” module for data acquisition.

3.1. „CALIBRATOR” Module

The “CALIBRATOR” module is intended for verification that the multimeter’s accuracy is consistent with the specifications provided by its producer. It also enables the appointment of corrective functions needed for calculation of corrected values X_p .

By selecting this module in the start screen of the “CAL-DAQ” software, an additional ribbon is created in an open MS Excel sheet, as shown in Figure 2.

Individual buttons are placed on this ribbon in an order that facilitates implementation of the calibration procedure. This procedure is carried out interactively by the operator and PC.

Figure 2 presents a “ribbon” that appears in MS Excel sheet after activating the “CALIBRATOR” module.

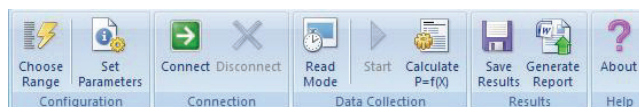


Fig. 2. “Ribbon” of “CALIBRATOR” Module

Starting from the left side, the individual buttons carry out the following functions:

a/“Choose Range” – prepares software for calibrating the multimeter on the chosen range

b/“Set Parameters” – enables the entering the data as: serial number, inventory number, temperature, humidity, and full name of the operator

c/“Connect” – conducts a control test to check communication of calibrated multimeter with PC

d/“Disconnect” – enables disconnection of communication with PC

e/“Read Mode” – enables the setting of continuous read data in set time intervals, or read in defined cycles with set number “n” of repeated measurements

f/“Start” – starts data acquisition in calibration while taking into account previously set conditions and read mode

g/ “Calculate $P=f(X_{rdg})$ ” points of the corrective function based on collected data

h/ “Save Results” – enables the user to save calibration results in a separate MS Excel sheet, which is standardized in such a way that these results can be downloaded to the metrological database [6]

i/ “Generate Report” – enables the generation of a report with calibration results in MS Word. The graph of the correction function shown in Figure 3 is one of the elements of this report.

One of the elements of this report is the graph of the correction function shown in Figure 3.

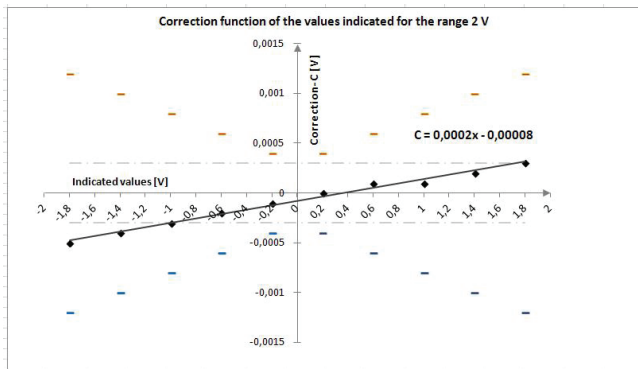


Fig. 3. Graph of the corrective function (17) determined for multimeter M4650CR No. CG710380 in range of 2 V-DC. (Element of the report from CALIBRATOR module)

A graph of the corrective function, shown in Figure 3, is a element of the calibration certificate generated automatically by “CALIBRATOR” module. The determined corrective function in the form of a graph and mathematical expression $P = 0.0002X - 0.00008$, enables quick evaluation of the accuracy of the calibrated multimeter with regard to the accuracy specified by its producer. It is possible to clearly see that accuracy of the multimeter subjected to verification is not worse than the declared accuracy by the producer. The mathematical figure of the corrective function appointed and revealed on the graph, can be entered into the “ACQUIRER” module, in which it will be used for correction of systematic errors during data acquisition carried out with the same multimeter operating under the control of this module.

3.2. „ACQUIRER” Module

This module was created on the basis of its first version [12] and improved version [14], and next refined so as to support correction of systematic errors and verification of the indication’s accuracy in terms of possibility to apply the expression (23) for estimating the standard uncertainty with the type B method. Figure 2 presents

a “ribbon” of this module that appears in an opened MS Excel sheet after selecting the “ACQUIRER” option on the start screen shown in Figure 1.

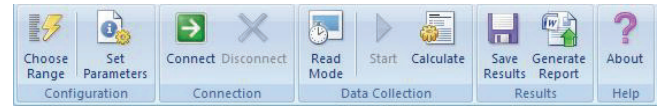


Fig. 4. “Ribbon” of the “ACQUIRER” module

The first buttons on “ribbon a, b, c, d” are the same as on the “ribbon” of the CALIBRATOR module shown in Figure 2, and they perform the same functions. The next buttons make it possible to carry out other activities specific to the “ACQUIRER” module.

“Read Mode” – enables acquisition of measurement results in defined cycles or under the procedure for constant measurements repeated in established time intervals

“Start” – starts calculation and acquisition of their results obtained on the selected measurement range of the multimeter

“Calculate” – starts calculation of the value of ends interval constituting the final result using formulas described in Chapter 2 (20), (21) or/and (22), (23)

“Save Results” – enables the user to save collected measurement results in separate MS Excel file

“Generate Report” – generates the final report automatically

This report includes descriptive statistics of the vector of collected data, components of correction function and enumerated values of the ends of the interval, which is the final measurement result.

The report also includes a diagram, which is a graphical interpretation of the measurement result. This interpretation allows for quick verification of the accuracy of the final measurement result in terms of meeting requirements (2) and possibility to apply the formula (24) for estimating the standard uncertainty with type B method.

Figure 5 presents an element of the report, which is a table that contains values of all calculated components needed to express the final measurement result: improved value x_p , ends of interval $[x_l, x_u]$, and reference value x_{ref} , which was connected to the input of the multimeter M4650CR, set on the range 2 V, DC.

This final measurement result, which is shown in Figure 5, was obtained taking into account the corrective function shown in Figure 3.

Below the table is a diagram that shows graphically the final measurement result. An evaluation of the correctness of the obtained result is presented in the last column of the table. The software evaluated the obtained result as correct. This is consistent with the situation shown on the diagram, in which measured reference value $x_{ref} = 1.9500005$ V with negligible small uncertainty is covered with ends of the interval representing the final measurement result. The reference value has been set on the FLUKE 5522A calibrator.

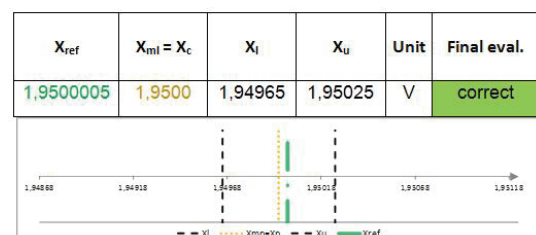


Fig. 5. Element of the report from “ACQUIRER” module confirming the credibility of obtained measurement results expressed in the range $[x_l, x_u]$

Figure 6 shows the view of laboratory stand on which “CAL-DAQ” software was tested.



Fig. 6. Laboratory stand on which CAL-DAQ software was tested

On the left side of Figure 6 a PC with launched “CAL-DAQ” software is shown. On the right side is a source of reference values with negligible small uncertainties. This source consists of the FLUKE 5522A calibrator and the FLUKE 8508A reference multimeter placed on the calibrator. Under the calibrator a M4650CR multimeter cooperating with “CAL-DAQ” software is visible.

4. Conclusions

Obtained results confirmed the validity of assumptions on the basis of which the “CAL-DAQ” software have been developed and launched.

Built-in algorithms to verify the accuracy of multimeter indications working under the control of this software were checked and can be used to create similar software.

It will be possible to carry out a full validation of used algorithms and logical structure of the software after developing in other environments of similar type of software that cooperates with other multimeter.

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