Conducting Calibration Measurements Based on the Virtual Standards® Technology

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***Abstract*-**The authors propose to use the Virtual Standard® technology in conducting calibration operations for a wide range of measurements. The Virtual Standard® technology is a universal technology for determining and introducing corrections in measuring device readings to reduce their errors. Theoretical principles underlying the Virtual Standard® technology are discussed, and their operation flow chart and some experimental findings are provided.

Key words: calibration, self-calibration, reading corrections, measurement result ambiguity, virtual standard.

1. Introduction

The problem of finding means of and methods for improving measurement accuracy often arises in measurements conducted during calibration. An individual adjustment of measuring devices provides an opportunity for solving this problem, in particular when one does not want to pay extra money for precise measuring devices. Appropriate standard and adjusting devices are required to achieve that. The Virtual Standard® technology has been developed to adjust measuring devices so that measurements could be conducted with a higher class of accuracy, but without using standards or adjusting devices.

Modern measuring devices consist of transducers in both hardware and software implementations, and remote measurement technologies, including Internet-based ones, spread broader and broader. Higher measurement accuracy is achieved through increasingly correct and precise measurements. Software has traditionally been used to improve measurement accuracy through improving precision i.e., to reduce the random error component. The most popular processing methods used for that purpose are various statistical processing and filtering algorithms. However, the question whether software can be used to increase correctness i.e., to take into account the systematic error component, and what processing methods should underlie such software, remains open. This work is designed to answer this question.

2. Target setting

The measurement object and the measuring device (SI) often interact in the potential field of the measurement object, which is accompanied by potential energy transformation between two points with different potentials on the measurement object into other forms of energy in the measuring device. The measuring device disturbs the measurement object and introduces errors in measurement results.

The principal meaning of the measurement procedure is converting a closed reciprocal 'measurement object – SI' system that is isomorphic in terms of abstract algebra into a one-way (homomorphous) system. The true value of the measured quantity corresponds to this ideal state with one-way (homomorphous) 'measurement object – SI' links. The actual value of the measured quantity differs from the true value by the measurement error.

Let us suppose that a set of values of measured quantity S is observed on the measurement object over measurement time t_i, and a set of measurement results J is registered at the measuring device output. Let

$$S = \begin{vmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{vmatrix} \tag{1}$$

where s_{11} and s_{21} are values of the measured quantity in the first point on the measurement object with potential φ, for example, on the first (positive) contact of a DC EMF source at moments of time t_1 and t_2, respectively;

s_{12} and s_{22} are values of the measured quantity in the second point on the measurement object with potential -φ, for example, on the second (negative) contact of a DC EMF source at moments of time t_1 and t_2.

Then

$$J = \begin{vmatrix} j_1 \\ j_2 \end{vmatrix} \tag{2}$$

where j_{11} and j_{12} are DC voltage values at moments of time t_1 and t_2.

In this example, the measuring device (DC voltmeter) is described by linear operator T:

$$T = \begin{vmatrix} 1 & 0 \\ 0 & -1 \end{vmatrix} \tag{3}$$

$$J=T \cdot S \cdot D \tag{4}$$

$$D = \begin{vmatrix} d_1 \\ d_2 \end{vmatrix} \tag{5}$$

where d_1, d_2 is an operator describing the nature of conversion (for example, voltage growth at the input amplifier or voltage reduction at the input divider, etc.) at the moment of time t_1, t_2.

Linear operator T (3) perturbations due to external factors are present in the real technical measurement process:

$$T(\chi)=T+\chi \cdot T' \tag{5}$$

where χ is a scalar parameter assumed to be sufficiently small, T′ is a perturbation caused by external factors.

T(χ) type linear operators are known to be characterized by multi-valued eigenfunctions with two branches [1]. Article [1] also presents the result of an analytic study of eingenvalue perturbation for perturbed operator (3) of the form

$$T(\chi) = \begin{vmatrix} 1 & \chi \\ \chi & -1 \end{vmatrix} \tag{6}$$

Two possible sets of measurement results correspond to a single set of true values of the measured quantity on object.

If we present measurement results as a function of an unknown random error component and an unknown systematic error component, then the equation in a single set of measurement results is unsolvable (one equation in two unknown quantities). If we consider measurement results as multi-valued sets, we obtain a system of several (two) equations in two unknown quantities: the random and systematic measurement error components. Such system is solvable, which enables an estimate to be obtained of the true value of the measured quantity and corrections to be formed for the measuring module reading that increase measurement result correctness. The linear independence of system equations, similar to the formation of a multi-valued set, is ensured by the conclusions of the T.Kato perturbation theory for linear operators. These results underlie the Virtual Standard® functioning algorithm.

3. Mathematical algorithm of the Virtual Standard®

Fig. 1 shows a flow chart of mathematical algorithm operation. Once a physical quantity has been measured on the object, and the measurement results have been digitized, they are fed to the processing module where they are saved in a certain memory domain where Y_1, the first subset of the multi-valued set of measurement results, is formed. Then coefficients $\{a_1,\ldots, a_n\}$ are formed with due regard to eigenvalues calculated by Kato for the multi-valued function linking the true value of the measured quantity on the measurement object to the elements of the multi-valued set of measurement results, which are used to calculate auxiliary set Y_2 of measurement results that is saved in the processing module memory. Thus, a series of multiple measurements is carried out as a function of the increasing/decreasing measured parameter, which results in the formation of two linearly independent subsets Y_1 and Y_2 of the multi-valued sets of measurement results. Then a target function is formed using the minimax criterion:

$$P(d(\bullet)) = \sup_{a \in X \times \Delta X} \min(\pi^{\alpha}(a_i) \,|\, l(d(a_i)) \quad (7)$$

For example, minimum relative deviation $l(d(a_i))$ from the optimum value of the functional dependence $\pi^{\alpha}(a_i)$ sought with respect to its maximum possible value in this dimension and limit domain ΔX (for example, formed in the measuring device tolerance domain) can be used as such criterion for finding an unambiguously defined functional dependence of values Y_1 and Y_2 from the unknown systematic and random error components with the target function and limit domain being placed in the processing module memory. At the next stage, coefficients $\{a_i\}$ are calculated and determined as results of performing the task of using formula (7) to optimize an unambiguously defined functional dependence $Y_1,Y_2=\Psi(\Delta_{random}, \Delta_{syst)}$ of values Y_1 and Y_2 from the unknown systematic and random error components, and the calculated coefficient are saved in the digital module memory. Then individual corrections are calculated for measurement results Y_1 with due regard to the real measuring device error using known coefficients of the unambiguously determined functional dependence from the digital module memory. The individual correction calculation results are used to determine the actual value of the measured quantity induced by the processing module as a measurement result.

4. Experimental results

The above-described algorithm has been implemented in the form of a software package and tested in over 250 series of various measurements. Some Virtual Standard® test results are given in this work as an illustration, which have been obtained in measurements of DC voltage and pressure. The following measurement ranges were used in tests on DC voltage measurements: 400 mV, 4 V, 40 V and 400 V. Escort 2010 multimeter (0.06% - 0.16%) was used as a measuring module, and V1-18 calibrator (0.002%) was used as a working standard. Virtual Standard® accuracy amounted to 0.01% - 0.05% in these experiments. The result observed was accuracy improved by a factor of 3 to 6 (Figs. 2).

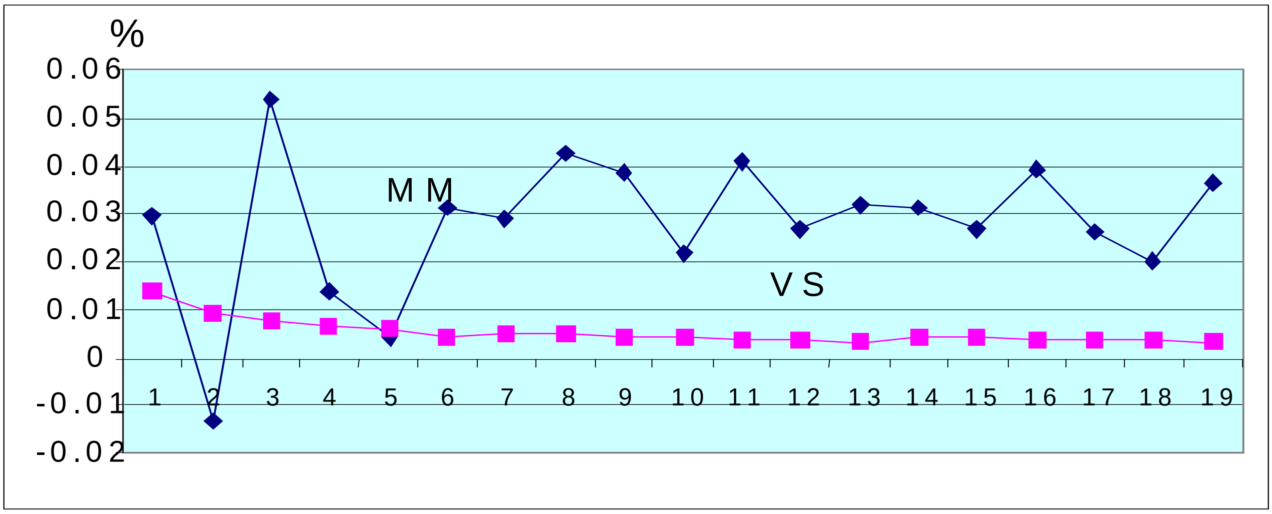

Fig. 2. DC voltage measured using Virtual Standard® system with Escort 2010 up to 400 mV as a measuring module: MM = Measuring Module; VS = Virtual Standard

5. Conclusions

The theoretical and experimental results presented suggest that measurement accuracy can be fundamentally improved in a series of various measurements using the Virtual Standard® technology. What are the principal technical measurement tasks that can be performed using the Virtual Standard® system? We are of the opinion that this will be calibration/self-calibration of measuring devices and transducers in the first place. The use of the Virtual Standard® system reduces costs and improves the functionality of calibration operations so much that they can be carried out as frequently as required to use calibration as an efficient tool for improving measurement accuracy. Thus, an opportunity arises to implement a broader range of calibration measurements using the Virtual Standard® technology: electric measurements, thermometric measurements, pressure measurements, liquid flow measurements, gas flow measurements, and a series of other types of measurement of various ranges and accuracies.

Reference

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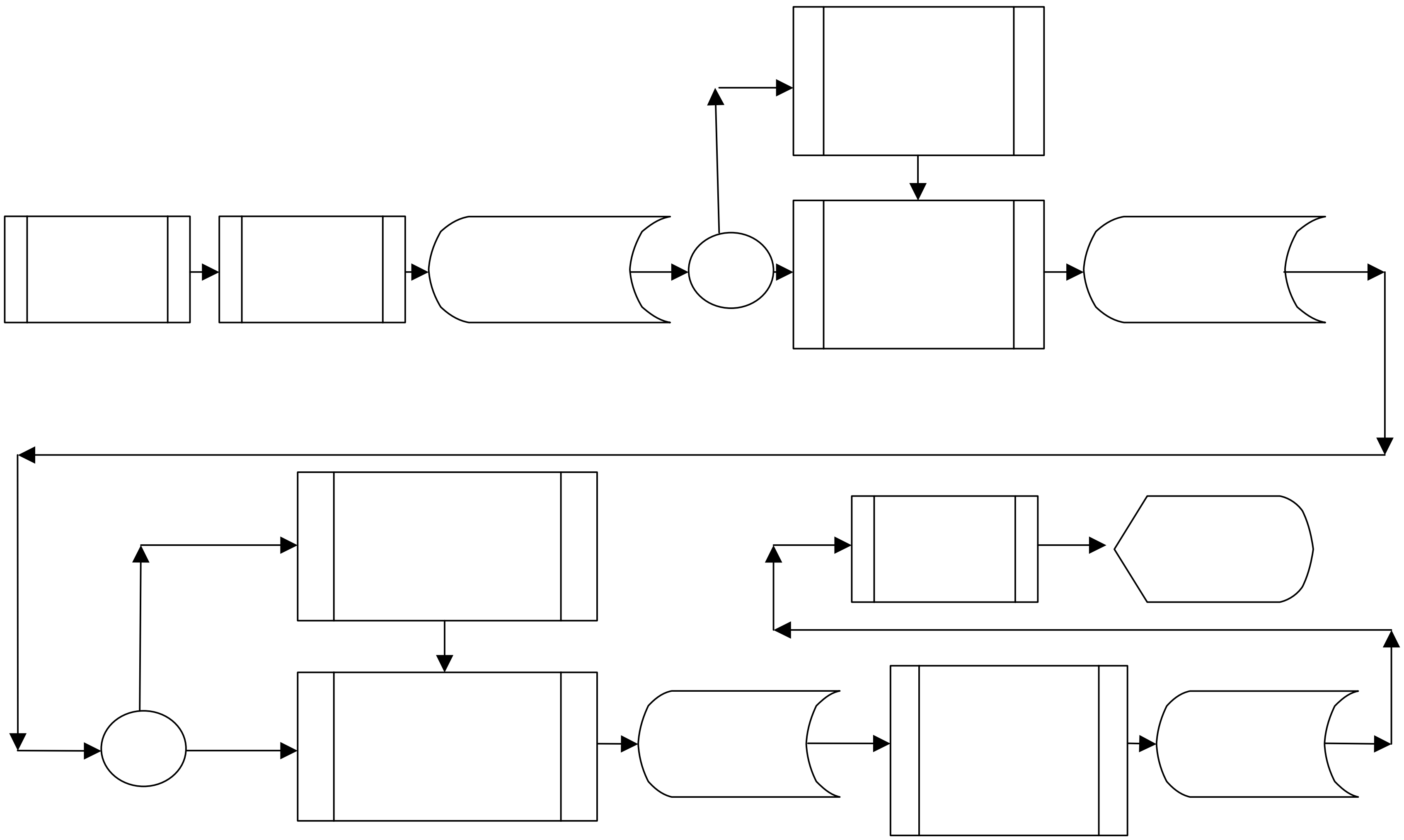

Fig.2. Virtual Standard algorithm