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Considerations regarding the factors involved in calibration of DC voltage standard calibrator

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Abstract - The estimation of measurement uncertainty is a compulsive task of each metrological laboratory which has implemented the quality system. This paper describes the factors which can influence the process of calibration of a DC voltage standard calibrator, the method for calculating the true value of the measured and the estimation of the measurement uncertainty.

Keywords: Standard calibrator, calibration, true value, measurement uncertainty.

I. INTRODUCTION

The implementation of a quality system represents one of the main requirement which must be satisfied if the recognition in conformity with SR EN ISO 17025 [1] of metrological laboratory is desired. The recognition of the quality system by an accreditation organization demonstrates that the laboratory meets the standards of quality and technical competency imposed by SR EN ISO 17025. The accreditation is based upon this agreed standard with specified measurement parameters and uncertainties. The estimation of the measurement uncertainties and the assurance of the traceability to SI of all the standards used are compulsive requirements for the laboratory mentioned above.

The article refers to calibration [2] of calibrators, on the functions of generating DC voltage within the (0 ... 1000) V range.

Digital multimeter and meter calibrators are multiple use instruments found in most calibration and standards laboratories.

Digital multimeter and meter calibrators provide the functions needed to calibrate DMMs and other meters. As DMMs have grown in functionality, metrology laboratories found that an ensemble of single function calibrators was required to calibrate the DMMs. The newest models are multifunction calibrators that provide all or nearly all of the functions needed to calibrate most DMMs.

A typical multifunction calibrator provides one or more quantities: direct and alternative current and voltage, electrical resistance stimulus.

Voltage calibrators, direct current and resistance calibrators are apparatus providing voltages, direct current and electrical resistances of scalable or direct variable known and fixed values, at the output terminals.

Single function calibrators can be used to complement the multifunction calibrator to provide additional functions, such as capacitance, inductance, and frequency stimulus as well as thermocouple and resistance temperature detection emulation.

Calibrators are designed for calibration and verification of apparatus measuring voltage and current (analogical and digital voltmeters and ampermeters) or electrical resistance (generally, digital multimeters).

From the point of view of displaying the generated value, calibrators may:

- display the generated value on decades and levels
- display the generated value on a digital display

II. CALIBRATION

A. *Technical operating conditions*

Reference conditions:

- environment temperature (23 ± 2) ^{O}C, unless technical specification provides otherwise
- relative humidity (50 ± 15) %, unless technical specification provides otherwise

If reference conditions are not complied with, calibration is stopped.

The generation error of calibrators in reference conditions should not exceed the error provided in the technical specification of the apparatus. For some calibrators, technical book provides the expanded uncertainties; in such case uncertainties determined are compared with the ones in the specification.

The value generated by the calibrator, when all decades indicate zero, or when display indicates zero, should not exceed the value provided by the technical specification.

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B. *Calibration method*

Methods used for the calibration [5] are:

- substitution
- direct comparison
- indirect comparison

The selection of method is made according to the accuracy of the calibrator to be calibrated and the measured quantity.

For the calibration of calibrators on the function to generate electrical direct voltage, we can use two methods:

- substitution, for calibrators with high accuracy
- direct comparison, for calibrator with lower accuracy.

For calibration of high-accuracy calibrators on the function to generate direct voltage, the multiple-function calibrator, is used as standard, and the digital multimeter with 8 ½ digits or 7 ½ digits is used as measuring mean.

The assembly method is shown in "Fig. 1".

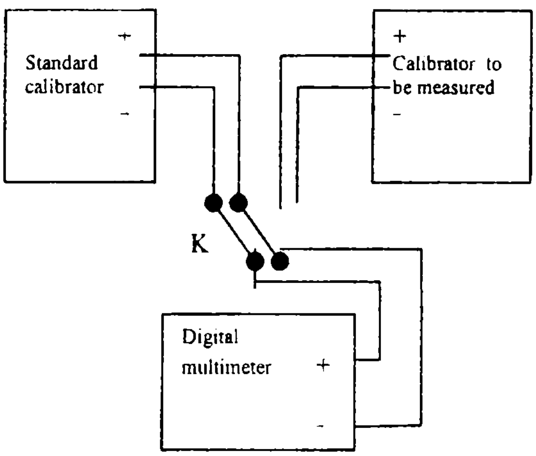

Fig. 1 Assembly in case of substitution

Most often, the calibration process may include three approaches of the calibration, depending on the customers' requests and level of information:

a) calibration before adjustment, in case we notice errors more significant than the measurement errors provided in the technical specification of the apparatus to be calibrated
 -adjustment (manual or using a software)
 -calibration after adjustment

b) calibration

c) adjustment, when the Customer knows that the apparatus must be adjusted and informs the laboratory thereof
 - calibration

If errors are more significant than the ones admitted by the technical book, the calibrator will be adjusted, if possible, and the errors determined prior and after adjustment will be specified in the calibration certificate.

C. *Determining the value of the measurand*

The true values of the calibrators are determined in the reference conditions.

In the absence of other indications, the zero adjustment is made on the smallest interval (if possible).

Calibrator will be calibrated to the best accuracy, corresponding to long-term stability.

We use standards ensuring:

- stable values of generated quantities
- required resolution
- measurement intervals to cover generation intervals of the calibrators to be calibrated
- required accuracy/uncertainty

Determining the value of the measurand and data processing, for the calibration of calibrators on the functions of generating direct voltage using the substitution method.

The calibrator generates direct voltages for each measuring point; they can be read on the digital multimeter display.

We conduct n readings for each _ oint, in conditions of repeatability. We calculate the average $\overline{X_X}$.

For the same measuring points, standard calibrator generated voltages measured with the same multimeter. We conduct n readings for each point, in repeatability conditions. We calculate the average $\overline{X_E}$.

We determine the true value [2] according to formula:

$$X = X_N + (\overline{X_X} - \overline{X_{OX}} + \delta X_{TX}) - (\overline{X_E} - \overline{X_{OE}} - \delta X_E - \delta X_{DE} - \delta X_{TE}) + \delta X_R + \delta X_X \quad (1)$$

where:

X_N	the nominal value displayed on the calibrator to be calibrated
$\overline{X_X}$	average value for n direct voltages values generated by the calibrator and read on a digital multimeter with resolution appropriate for measuring
$\overline{X_{OX}}$	average value for *n* zero direct voltages generated by the calibrator and read on the same digital multimeter having the same resolution
δX_{TX}	correction of calibrator due to environment temperature
$\overline{X_E}$	average value for n direct voltages generated by the standard calibrator read on the same digital multimeter, with resolution appropriate to measuring
$\overline{X_{OE}}$	average value for n zero direct voltages generated by standard calibrator and read on the same digital multimeter having the same resolution

δX_E	the correction of the value of the standard (the values in the calibration certificate)
δX_{DE}	correction due to time drift of the standard
δX_{TE}	correction of standard calibrator due to environment temperature
δX_R	correction due to variations of the supply network
δX_X	correction due to instability of the value displayed by the digital multimeter

In formula (1), the first bracket represents the basis for the calculation of the value indicated by the calibrator to be calibrated.

Each element in formula (1) has a certain value and a related uncertainty [3, 4].

a) average value $\overline{X_X}$, for direct voltage generated by the calibrator, for n readings made on the digital multimeter, in conditions of repeatability, is calculated according to the formula:

$$\overline{X_X} = \frac{\sum_{i=1}^{n} X_{Xi}}{n} \quad (2)$$

Uncertainty of element $\overline{X_X}$

is calculated:

$$u(\overline{X_X}) = \sqrt{\frac{\sum_{i=1}^{n} (X_{Xi} - \overline{X_X})^2}{n(n-1)}} \quad (3)$$

b) values and uncertainties for terms $\overline{X_{OX}}$, $\overline{X_{OE}}$ are calculated with formulas similar to formulas (2) and (3).

c) average value $\overline{X_E}$ for n readings conducted with the same digital multimeter, when voltage values (delivered by standard calibrator) values are calculated by formula

$$\overline{X_E} = \frac{\sum_{i=1}^{n} X_{Ei}}{n} \quad (4)$$

Uncertainty of element $\overline{X_E}$

is calculated:

$$u(\overline{X_E}) = \sqrt{\frac{\sum_{i=1}^{n} (X_{Ei} - \overline{X_E})^2}{n(n-1)}} \quad (5)$$

d) The correction of the value of the standard δX_E - the difference between the nominal value and the value in the calibration certificate of the standard used.

Uncertainty of element δX_E.

The value of the measurement uncertainty $U(\delta X_E)$ provided in the calibration certificate of the standard calibrator,.

e) Correction due to drift in time of standard δX_{DE} is taken into account depending on the data provided by the history of the standard used.

Uncertainty of element δX_{DE}.

Based on the history of the standard, a time drift a is evaluated. The associated uncertainty is calculated as:

$$\delta X_{DE}) = \frac{a}{\sqrt{3}} \quad (6)$$

f) Correction of standard calibrator, due to environment temperature δX_{TE} is applied only when measurements are conducted at a temperature differing from the reference temperature and the technical book provides temperature correction coefficients c_{TE}, for standard calibrator

$$a = c_{TE}\,(T - T_0) = \delta X_{TE} \quad (7)$$

Uncertainty of element δX_{TE}.

Applicable only in case the measurement temperature differs from the reference temperature. In such case, we measure temperature T to which we have noticed a variation a.

$$u(\delta X_{TE}) = \frac{a}{\sqrt{3}} \quad (8)$$

g) Correction of calibrator, due to environment temperature δX_{TX} is applied only when measurements are conducted at a temperature differing from the reference temperature and the technical book provides temperature correction coefficients c_{TX}. The value of "a" is calculated with a formula similar to formula (6).

Uncertainty of element δX_{TX}.

Applicable only in case the measurement temperature differs from the reference temperature. In such case, we measure temperature T to which we have noticed a variation a.

$$u(\delta X_{TX}) = \frac{a}{\sqrt{3}} \quad (9)$$

h) Correction due to variations of the supply network δX_R. No correction is applicable, thus

$\delta X_R = 0.$

Uncertainty of element δX_R.

We estimate the modification of the multimeter indication (± a) when there are instabilities in the supply network. The uncertainty is estimated:

$$u(\delta X_R) = \frac{a}{\sqrt{6}} \tag{10}$$

i) Correction due to instability displayed by the multimeter to be calibrated δX_X. Generally, no correction is applicable, thus $\delta X_X = 0$.

Uncertainty of element δX_X.

We estimate the modification of the multimeter indication (± a) due to its own instability (depends on the apparatus resolution). The uncertainty is estimated:

$$u(\delta X_X) = \frac{a}{\sqrt{3}} \tag{11}$$

The composed standard uncertainty is calculated:

$$u_c(X) = \sqrt{\sum u^2(X_i)} \tag{12}$$

The expanded standard uncertainty (for k = 2) associated to the value of measurand is:

$$U = k \times u_c(X) \tag{13}$$

The standard uncertainty:

$$u_c(X) = \sqrt{\sum u^2(X_i)} = 2.9\mu V$$

The expanded uncertainty [3, 4] was calculated using a coverage factor $k = 2$, which correspond to a confidence level of ≈ 95%:

$$U = k \times u_C = 2 \times 2.9 = 6\ \mu V.$$

The reported results are: X = $0.999\ 977\ V$,
$U = 6\ \mu V$

An example for estimation of standard uncertainty for multifunction calibrators for 1 V, is shown in table 1

Table 1

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensibility coefficient c_i	Uncertainty contribution $u_i(y)$
X_N	1 V	0			0
$\overline{X_X}$	0.9999740 V	0.086 μV	Normal	1	0.086 μV
$\overline{X_{OX}}$	-0.0086 mV	0.086 μV	Normal	1	0.086 μV
δX_{TX}	0	0	Rectangular	1	0
$\overline{X_E}$	-0 9999923V	0.011μV	Normal	1	0.011μV
$\overline{X_{OE}}$	0 0045 mV	0.011μV	Normal	1	0.011μV
δX_E	-0.0000008V	0.6μV	Normal	1	0.6μV
δX_{OE}	0	2 8μV	Rectangular	1	2.8μV
δX_{TE}	0	0	Rectangular	1	0
δX_R	0	0.24μV	Triangular	1	0.24μV
X	0.999 976 8 V				2.9 μV

III. CONCLUSIONS

To calculate the true value of the measurand and to estimate the measurement uncertainty represent two essential requirements for traceability assurance.
The influence of each of the quantities mentioned in this paper is different from a measurement method to another.
Thus, for each method of measurement the uncertainty has to be calculate in a particular way.
According with SR EN ISO 17025:2001 authorized or accredited metrological laboratories have their own calibration procedures which include how to estimate the uncertainty for the measurement method used.

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