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THE INFLUENCE OF THE ENVIRONMENTAL TEMPERATURE CONCERNING THE MEASUREMENT UNCERTAINTY AT DIGITAL MULTIMETRES CALIBRATION

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Abstract **– The article presents the regime of the digital multimeters in the calibration process when the operating conditions are different from the reference conditions.**
It presents the mathematical model for evaluating and expressing the measurement uncertainty of the electronic measuring instruments with digital display.
The measurement uncertainty wich is influenced by the environmental temperature it modifies when the environemental temperature changes and influences this way the measurement results.

Keywords: *measurement uncertanty, variance compose, operating conditions, digital multimeter.*

1. INTRODUCTION

Digital multimeters (DMM) are electric measuring instruments which supplie the result of the measurement as a digital value on a display.
The error of measurement, as difference between the result of a measurement and the true value of the measurand, is inevitable, for multiple resons:
- the imperfection of means and method of measurement;
- variation of the environmental conditions;
- exterior perturbations;
- subjetctivity of the operator etc.

Moreover, the true value, is in itself unknown and rigously undetermined.
For these reasons any measurement is influenced by an uncertainty.
The digital dispay, of the measurement result, is easely and safely read by the operator, and allows the subiective reading errors to be eliminated. This is the benefit which the digital meters bring to the measurement process in comparison to the analog measuring meters.
The digital measuring meter uses discrete signals. These signals can be sent, converted and processed with greater accuracy and safety than continuous signals.
They also have a greater immunity to disturbances and are directly compatible with access to a computer.

2. THE EVALUATION OF MEASUREMENT UNCERTAINTY FOR DIGITAL MULTIMETERS PREPARATION OF PAPERS

The Calibration Measurement Capability (CMC) of the National Institute of Metrology from Romanian Bureau of Legal Metrology (BRML-INM) concerning the DMMs is:
for U_{AC} = 20 mV.750 V; f = 10 Hz…300 kHz ; U = 60 x 10^{-6} … 1.6 x 10^{-3}, for I_{AC} = 10 mA…10 A ; f =10 Hz…10 kHz ; U = 210 x 10^{-6} …7 x 10^{-3},
where U is the extended uncertainty for a confidence level P= 95%; coverage factor, k =2.
The standard, used in the Electrical Measurements Laboratory of the INM, to disseminate the unit for AC voltages and AC currents is a multifunction calibrator FLUKE 5720A with a FLUKE 5725A amplifier. This standard is traceable to SI according the Calibration Certificate, No. 2006.00777, issued by UME - Tubitak –Turkey.

The Electrical Measurements Laboratory of INM is accredited with Accreditation Body of Deutscer Kalibrierdienst (DKD) at Physikalisch- Technische Bundesanstalt (PTB) as calibration laboratory according to DIN EN ISO/IEC 17025:2005 for calibration in the fields: DC voltage, DC current, DC resistence, AC voltage, AC current, AC resistence, capacitance, inductance, dissipation factor.
The error of measurement, E_x , of DMM to be calibrated is obtained from the relationship [1]:

$$E_x = V_{Xmed} + \delta V_X - V_S - \delta V_{SD} - \delta V_{ST} \quad (1)$$

where:

V_{Xmed} - average value for n readings on the multimeter to be calibrated;

δV_X - correction due to resolution and short instability of the value displayed by the multimeter to be calibrated;

V_S - voltage or current value output by the standard calibrator (the calibration certificate shall be used);

δV_{SD} - correction of drift in time for the standard calibrator;

δV_{ST} - correction of the value output by the standard calibrator due to environmental temperature;

The manufacturer's specifications corresponding to the highest measurement accuracy are given in the technical book of the instrument.

Each element of the formula (1) has value and a standard uncertainty.

3. THE INFLUENCE OF THE ENVIRONMENTAL TEMPERATURE CONCERNING THE MEASUREMENT UNCERTAINTY

The specifications corresponding to the highest measurement accuracy, for an Agilent DMM, type 34401, are the following:

- heat-up time until the instrument is in a stable thermal state: 1 hour;
- maximum number of digits for the display of the measurement result: 6½ digits;
- filter set for the slow AC option: ON
- input signal: sine waveform

The environmental reference conditions for a DMM calibration are:

- reference temperature: $23^0C \pm 5^0C$
- power supply: 220 V± 10%
- line frequency: 45 Hz to 66 Hz.

One should bear in mind the fact that, typically, a digital multimeter comes with the default settings of the manufacturer, which, in most cases, do not provide the best accuracy the instrument is capable of. Therefore, in order to get the optimum performance of the instrument for a given application, the operator has to carefully set the multimeter accordingly, following the procedures given by the manufacturer in the technical manual of the instrument.

Example: In order to obtain the best accuracy specificied in the user's book, the measurement configuration for the Agilent DMM, type 34401, is done as follows:

Step 1. Power: ON;
Step 2. Function: Shift - ACI for AC current or
Shift - ACV for AC voltage;
Step 3. Shift - MENU
A: MEAS MENU > B: MATH MENU…
V COMMANDS
1:AC FILTER > 2: CONTINUITY…
V PARAMETER
FAST: 200 Hz > MED: 20 Hz > SLOW: 3 Hz
ENTER
Step 4: Shift - MENU
A: MEAS MENU > B: MATH MENU…
V COMMANDS
1:AC FILTER
> 2: CONTINUITY > …
> 5: RESOLUTION
V PARAMETER
FAST 4 DIGIT
> SLOW 4 DIGIT
> FAST 5 DIGIT
> SLOW 5 DIGIT
> FAST 6 DIGIT >
SLOW 6 DIGIT
ENTER

At the same time, in order to calibrate the DMM, the programming of the standard calibrator, Fluke 5720A, is done as follows:

Step 1: Power: ON
Step 2: Programming the range, the output of the standard multifunction calibrator:
3 A; f = 1 kHz / STANDBY
Step 3: Setup MENUS Λ

DONE setup	Cal	Self Test & Diags	Instmt Setup	Instmt Config	Special Functns	

5. Λ PREV MENU 1. Λ

DONE Setting up	Format EEPROM	Spec Format Setup	Set Intrnl Clock	Boost Amp Types	Remote Port Setup	

4. Λ PREV MENU 2. Λ

DONE Setting **Spec Fmt**	Cal Interval 24 HOUR Λ 90 DAY Λ 180 DAY Λ **1 YEAR**	**95 %**	Spec Confidence 99 %

3. Λ PREV MENU

After the measurement configuration of DMM and the programming of the standard calibrator, we can start the calibration, if the technical conditions, the metrological conditions and the references conditions are respected.
The accuracy of the standard calibrator is given in the technical book, for $T_0 = 23\ ^0C \pm 5^0C$, which represents the reference range.

The evaluating of the measurement uncertainty in calibrating an Agilent DMM, type 34401, in AC current, at 3 A. f = 1 kHz, will be exemplified.
For AC current range, at 3 A, f = 1 kHz output, the specifications in the technical book, for the used standard calibrator, Fluke type 5720A with a Fluke 5725A amplifier, are given in Table 1.

Range	Resolution	Frequency	Absolute Uncertainty ±(ppm output + μA)
			± 5^0C from calibration temperature,
			1 Year
11 A	100 μA	40 – 1 k	460 + 170
		1 k – 5 k	950 + 380
		5 k – 10 k	3600 + 750

Table 1 - AC Current Specifications: 95 %; Confidence Level

Particular care shall be taken when calibration is undertaken at sites other than a permanent laboratory facility.
In relationship (1), the correction of the value output by the standard calibrator, due to environmental temperature, δV_{ST} , is applied only when measurements are performed at a temperature diffrent from the reference temperature range, $T_o = 23\ ^0C \pm 5^0C$, and the technical book provides temperature correction coefficients c_{ST} . In such case, we measure temperature T to which we have noticed a variation $\Delta T = T - T_0$. Quantity $a = \Delta T \times c_{ST}$ represents an additional error, which contributes to the appearance of another component of the measurement uncertainty, as result of the variations of the environmental conditions, in this case, temperature. Thus, whenever the instrument is used at a temperature outside this interval, but still within the specified operating temperature range, the additional errors due to that difference in temperature have to be added to the tolerated errors.
The additional errors are determined depending on the frequency of the input signal and the temperature coefficient, given in Table 2.

Range	Frequency	Temperature coefficient	
		±(ppm output + μV)/ ^{0}C	
		10 ^{0}C – 40 ^{0}C	0 ^{0}C – 10 ^{0}C and 40 ^{0}C – 50 ^{0}C
11 A	40 – 1 k	20 + 75	30 + 75
	1 k – 5 k	40 + 75	50 + 75
	5 k – 10 k	100 + 75	100 + 75

Table 2 - Fluke 5720 A - Temperature coefficient

Practical example: If a Agilent, type 34401 digital multimeter is used at a temperature of 32 ^{0}C, to measure an AC current of 3 A, with the frequency of 1 kHz, in the repetability conditions.

According to Table 1, the uncertainty of the standard calibrator to the reference temperature $T_0 = (23 \pm 5)\ ^0C$ for 3 A; f = 1 kHz is:
± (460 ppm output + 170 μA) for a 95 % confidence level, k=2.
For this example, in relationship (1), the standard uncertainty, $u(\delta V_D)$, result of the drift of the standard calibrator Fluke 5720A, is:

$$u(\delta V_D) = (\frac{460 \times 3}{10^6}\text{A} + \frac{170}{10^6}\text{A})/2 = 0.000775\ \text{A};$$

V_{Xi} :
1. 2.99974 A
2. 2.99976 A
3. 2.99976 A
4. 2.99982 A
5. 2.99989 A

$$V_{Xmed} : \frac{\sum_{i=1}^{5} V_{xi}}{n} \quad ; \ n=5$$

$V_{Xmed} = 2.999796$ A

$$u(V_{Xmed}) = \sqrt{\frac{\sum_{i=1}^{n} (V_{xi} - V_{xmed})^2}{n(n-1)}} \quad ;$$

$u(V_{Xmed}) = 2.6944 \times 10^{-5}$ A.

$\delta V_X = 0$

$u(\delta V_X) = \frac{V_{Xi\max} - V_{Xi\min}}{2\sqrt{3}}$;

$u(\delta V_X)$ =0,0000433 A;

V_S : 3,00051 A

u(Vs)=(3 A x 150 μA/A)/2 x 10^6 ;

where 150 μA/A represents the extended uncertainty for AC current, to 3 A, f= 1 kHz, eveluated for 95 % confidence level; the calibration certificate of the standard calibrator is used.

u(Vs)=0.000225 A

$\delta V_{SD} = 0$

$u(\delta V_{SD}) = (460 \times 3\ A/10^6 + 170\ A/10^6)/2$;

$u(\delta V_{SD}) = 0.000775$ A.

The uncertainty budget for I(AC)=3 A, f=1 kHz, $T_0 = 23^0C \pm 5^0C$, is presented in Table 3

I (AC):3 A; f = 1 kHz			**Uncertainty budget**			
T=23ºC ± 5ºC						
Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y)$	Variance compose $u^2_i(y)$
$V_{X\ med}$	2.999796	2.69E-05	Normal	1	2.6944E-05	7.26E-10
δV_X	0	4.3301E-05	Rectangular	1	4.330E-05	1.88E-09
V_S	3.000510	0.000225	Normal	-1	0.000225	5.06E-08
δV_{SD}	0	0.000775	Normal	-1	0.000775	6.01E-07
E	-0.0007				0.000809	
Standard uncertainty $u_c(E) = \sqrt{\sum u_i^2(y)}$					0.8086	mA
Extended uncertanty : $U = k \times u_c(E) = 2 \times 0.8086$ mA =					1.617	mA
CMC (calibration and Measurement Compatibilities):					2.7	mA

Table 3 - Uncertainty budget, $T_0 = 23^0C \pm 5^0C$

According to Table 2, the additional error due to the temperature difference between the actual operating temperature T $(T = 32\ ^0C)$ and the reference temperature $T_0 = 23^0C \pm 5^0C$ is:

$\Delta T = T - T_0$

$\Delta T = 32\ ^0C - 28\ ^0C = 4\ ^0C$

$a = 4\ ^0C \times (\frac{20 \cdot 3}{10^6} A + \frac{75}{10^6} A) = 0.000540$ A

$\delta V_{ST} = 0$

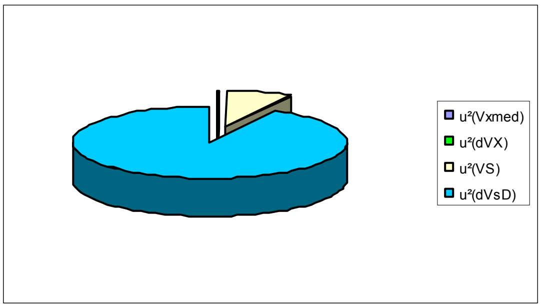
$u(\delta V_{ST}) = a/2\sqrt{3} = 4x(20 \times 3\ A/10^6 + 75\ A/10^6)/2\sqrt{3}$

$u(\delta V_{ST}) = 0.000156$ A

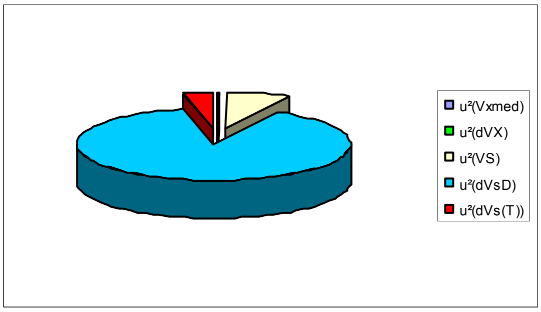
The uncertainty budget for I(AC)=3 A, f=1 kHz, $T_0 = 23^0C \pm 5^0C$, is presented in Table 4.

I (AC):3 A; f = 1 kHz			**Uncertainty budget**			
T=32ºC ($T \neq T_0$; T_0=23ºC ± 5ºC)						
Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y)$	Variance compose $u^2_i(y)$
$V_{X\ med}$	2.99980	2.6944E-05	Normal	1	2.6944E-05	7.26E-10
δV_X	0	4.3301E-05	Rectangular	1	4.3301E-05	1.88E-09
V_S	3.00051	0.000225	Normal	-1	0.000225	5.06E-08
δV_{SD}	0	0.000775	Normal	-1	0.000775	6.01E-07
δV_{ST}	0	0.000156	Rectangular	-1	0.000156	2.43E-08
E	-0.0007				0.0008235	
Standard uncertainty $u_c(E) = \sqrt{\sum u_i^2(y)}$					0.8235	mA
Extended uncertainty : $U = k \times u_c(E) = 2 \times 0.8086$ mA =					1.647	mA
CMC (calibration and Measurement Compatibilities):					2.7	mA

Table 4 - Uncertainty budget, $T = 32^0C$



a.



b.

Figure 1 Contribution of the partial variance in the compose variance

a. variances evaluated at $T_0 = 23^oC \pm 5^oC$
b. variances evaluated at $T = 32^oC$

The result of the measurement is: *E= - 0.7 mA* *U= ± 2.7 mA*
The increase of the uncertainty of measurement in DMM calibration, owing to temperature variation is 1.8%.

$u^2_i(y) = C_1u^2(V_{x\ med}) + C_2u^2(\delta V_X) + C_3u^2(V_S) + C_4u^2(\delta V_{SD}) + C_5u^2(\delta V_{ST})$

The contribution of the variance $u^2(\delta V_{ST})$ in the compose variance, $u^2_i(y)$, is 3.6 % , Figure 1.

4. CONCLUSION

As one can notice from the practical example considered above, performing measurements with such a digital multimeter in operating conditions, that are different from the reference conditions, introduces additional errors and also can notice the increase of the uncertainty of measurement. Whenever the instrument is used outside the specified reference intervals, special care should be taken into consideration for the additional errors due to the influencing environmetal factors such as temperature.
Using these measuring instruments allow for fast, highly accurate and reliable measurements, provided that the additional errors due to influencing factors, such as operating temperature, that have values outside the reference intervals specified by the manufacturer, are always properly calculated and added to the specified tolerated errors of the instrument.

The result of a measurement must be accompanied by the estimated uncertainty of measurement because otherwise it can be unappropriate for the proposed scope.
In the metrological activity it is necessary that the measurement uncertainty to be objectively estimated and specified together with the result of the measurements.
A calibrating certificate can not be used if it contains out the brut result of the calibration, without specifying the calibration uncertainty.
In order to have a coherent metrological system, it is also important that the same procedures are used to evaluate and calculate the measurement uncertainty, i.e., the ISO Guide (GUM).

References

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