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Errors Measurements Quantification in Analog Voltmeter

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--***ABSTRACT***--
This paper describes the procedure for quantifying the best estimate magnitudes errors of the measurement in an analog voltmeter, including the calculation of the combined standard uncertainty; the direct measurement comparation method is used, and the environmental and technical considerations necessary to perform a reliable procedure are mentioned. In addition, the numerical and graphical results, obtained experimentally, are shown for one range of an analog multimeter as a function of direct current voltmeter.

KEYWORDS;-*Measurement errors,uncertainty, voltmeter, analog,measurement comparation.*

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I. INTRODUCTION

The measurement processes are based on the determination of numerical values that contain a certain magnitude of error, which must be within the limits indicated by the accuracy of the measuring instrument.

The accuracy in a measurement process is defined as the proximity of the agreement between the result of a measurement and the actual value of the particular amount subject to measurement, this being the overall property from the point of view of errors.

The accuracy of an instrument is defined as the ability of the instrument to give numerical responses close to a true value. The accuracy is all the greater the closer to the actual value the numerical indications of the measuring instrument are [1].

It is necessary to know both the processes and the environmental and technical considerations to determine the magnitudes of the errors implicit in the measurements, which will allow validating the accuracy of the measuring instrument with an adequate level of confidence.

The realization of the measurement processes requires the control of the environmental conditions, since these influences the indications of the instruments, therefore it is necessary to know the characteristics and technical specifications of the different test equipment [2].

II. AMBIENTAL AND TECHNICAL CONDITIONS

Ambiental conditions

The environmental conditions must be controlled in such a way that neither the precision nor the stability of the instruments and/or equipment used are affected, lent out special attention to temperature, relative humidity, vibration level, cleaning, lighting, magnetic fields, electric fields, acoustic noise, etc.

The permitted values are established in the user manuals provided by the manufacturer of the measuring equipment and instruments, and in the respective regulations.

Depending on the accuracy required by the measurement, both the type and the degree of control are established, for example, the environmental conditions for high-precision instruments must be controlled more rigorously, than in an instrument of routine or common use [2].

Energy Source Characteristics

Neither instability nor total distortion due to harmonic content must contribute to the uncertainty of the measurement in more than one-tenth of the accuracy class of the measuring instrument under test, being stable for a minimum of 20 seconds, allowing the adequate collection of the readings of both the instrument under test and the standard.

Metering Pattern Accuracy

The determination of instrumental errors must be performed with some reference instrument, called a standard, which does not appreciably affect the magnitude to be measured, so that its errors can be neglected compared to the errors to be determined.

In general, it can be said that it is convenient to use measurement standards with an accuracy of at least four times better than the accuracy of the instrument under test, nevertheless, an accuracy greater than ten times is highly recommended [2].

Mounting

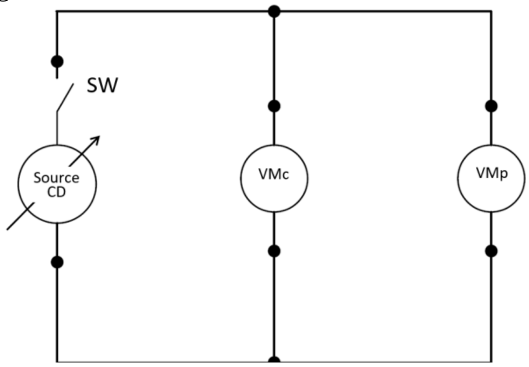
Portable instruments must try out on a non-ferrous platform in the operating position specified by the manufacturer, whether vertical, horizontal or inclined.
The dashboard instruments must be assembled on non-ferrous boards and following the manufacturer's instructions.

Thermal Stability

Both the instrument under test and the standard must indicate its full value keeping up the reference temperature stable long enough to eliminate temperature gradients, generally being a enough hour.

Method of Measurement

The direct comparison measurement method is the measurement system most used in the measurement of errors in measuring instruments of electrical quantities.
"Measurement method by direct comparison. Measurement method in which the magnitude to be measured is directly compared with a magnitude of the same nature, having a known value"[2].
In figure 1, the electrical diagram is shown.



Where:
SW -Switch
VMc -Voltmeter under test
VMp -Standard voltmeter

Figure 1. Electrical diagram connections.

Symbols and marks intoanalog instruments meters

The measuring instruments have marks on their cover, or on one of the external surfaces of their box, this set of marks and symbols indicate the magnitudes they measure, their scope, the type of source for energization, the number of measuring elements, its characteristics of use and its electrical characteristics, in addition to data related to the manufacturer.

In instruments with multiple functions and scopes, the respective information is indicated in the user manual, in which the manufacturer points out the specifications and characteristics of each function and scope of the instrument.

III. PROCEDURE FOR THE DETERMINATIONERRORSIN ANALOG VOLTMETER

Once the instrument is stabilized in its normal position of use and at the reference temperature, proceed as follows:

Adjust Pointer to Zero.

Before taking a reading, the index of the instrument should adjust to the mark indicating the zero position, as follows:

With the unit running, the position uses a screwdriver to adjust the pointer for the zero indication. While keeping the pointer at zero, slightly reverse the rotation of the screw to disengage it. This will reduce the effect of a pointer change in shock.

Thermal Conditioning.

Before collecting readings for error determination, the instrument under test must be energized at one hundred percent of its range, during one hour for instruments with an accuracy of 0.05% to 0.25%, and at least half an hour for instruments with an accuracy of 0.5% to 5.0%
After it has been thermally conditioned, the instrument indicator will reset to zero.

Reading.

Readings are collected at least six *k* points equidistant from the scale, including the zero mark (if marked on the scale) and the lower and upper marks of the scale. Immediately before taking a reading, the instrument case should be tapped lightly.

Subsequently, the voltage supplied to the measurement circuit will be varied with increasing values step by step to produce indications at the exact *k* points of the scale of the instrument under test, up to the upper limit of the range. Record all numerical figures indicated by the pattern for each of the values measured at points *k*. The procedure indicated above will be repeated with decreasing values at the same points *k*.

This operation will be carried out until the same amount of readings is obtained at each of the measurement points *k* on the scale of the instrument under test.

Errors quantifications and its measurement uncertainly.

The magnitude of the errors at each point *k* of the scale, where the full-scale value is included, i.e., the scope of the instrument under test, is determined with the appropriate definition of the mathematical model of the measurand:

$$\mathrm{e_k}(\mathrm{Lc_k}, \mathrm{Lp_k}) = \mathrm{Lc_k} - \mathrm{Lp_k} \qquad (1)$$

where:

$\mathrm{e_k}$ -error in the k mark of the scale of the voltmeter under test.
$\mathrm{Lc_k}$ -instrument reading under test.
$\mathrm{Lp_k}$ -standard instrument reading.

Uncertainly sources.

Considering that the procedure uses the method of measurement by direct comparison and the mathematical model of the measurand (1), and that in addition the temperature in the place where the experiment is carried out does not affect the accuracy of the standard instrument, that is, it can be discarded at the temperature of the following list of sources of uncertainty, thus remaining only:

- The accuracy of the standard voltmeter.
- The variability of the readings at each point k of the scale.
- The resolution of the voltmeter under test.

Uncertainly Standard type A.

The variability of the readings at each point k of the scale is evaluated, here it is calculated with the following statistical equations [3, 4]:

Mean value of the readings, $\overline{\mathrm{Lp_k}}$:

$$\overline{\mathrm{Lp_k}} = \frac{1}{10}\sum_{\mathrm{j}=1}^{10} \mathrm{Lp_j} \qquad (2)$$

Where:

$\mathrm{Lp_j}$ -measurements on the k mark of the standard voltmeter scale.

Experimental variance of readings, $\mathrm{s^2(Lp_k)}$:

$$\mathrm{s^2(Lp_k)} = \frac{1}{10-1}\sum_{\mathrm{j}=1}^{10} (\mathrm{Lp_j} - \overline{\mathrm{Lp_k}})^2 \qquad (3)$$

Estimated standard deviation, $\mathrm{s(Lp_k)}$:

$$\mathrm{s(Lp_k)} = \sqrt{\mathrm{s^2(Lp_k)}} \qquad (4)$$

Standard uncertainty type A, $\mathrm{U_A}(\overline{\mathrm{Lp_k}})$:

$$U_A(\overline{Lp_k}) = \frac{s(Lp_k)}{\sqrt{10}} \quad (5)$$

Uncertainly Standard type B.
In the voltmeter under test, the uncertainty is associated with the resolution of the indication of the measurement quantities on the instrument scale, and is calculated with the following equation [3]:

$$U_B(VMc) = \frac{\frac{\text{Resolution}}{2}}{\sqrt{3}} \quad (6)$$

Where:

Resolution $\frac{1}{10}$ of the value of the divisions on the voltmeter scale under test.

In the standard voltmeter, standard uncertainty type B for each point k of the scale is calculated using the following equation:

$$U_B(VMp)_k = \frac{U_E(VMp)_k}{\sqrt{3}} \quad (7)$$

Where:

$U_E(VMp)$ Accuracy of the standard voltmeter, according to the scope used.

The best estimation errors.
The best estimate of the error in each scale mark on the analog voltmeter under test is calculated as:

$$\overline{e_k} = Lc_k - \overline{Lp_k} \quad (8)$$

Where:

$\overline{e_k}$ mean of the errors in **k** point.
Lc_k value step measure in **k** point.
$\overline{Lp_k}$ mean measure voltmeter pattern in **k** point.

Combined uncertainly Standard.
To calculate the combined uncertainty at each point k of the scale, the following equation [3,4] is used:

$$Uc^2(e_k) = C1^2 U_B(VMc)^2 + C2^2 U_A(\overline{Lp_k})^2 + C2^2 U_B(VMp)_k{}^2 \quad (9)$$

Where, with equation (1):

$$C1 = \frac{d(e)}{dLc} = \frac{d(Lc - Lp)}{dLc} = 1.$$

$$C2 = \frac{d(e)}{dLp} = \frac{d(Lc - Lp)}{dLp} = -1.$$

Then:

$$Uc(e_k) = \sqrt{Uc^2(e_k)} \quad (10)$$

Finally, the result of the errors in each point k on the scale of the instrument under test is expressed as [4]:

$$e_k \pm Uc(e_k) \quad (11)$$

IV. EXAMPLE CASE: TEST AND RESULTS

- Calculate the best variation of errors, including their combined uncertainty, for the 15 [V] range of a Triplett ™analog multimeter, model 60 NA, in the direct current voltmeter function (VMc-VD).
- Drawn the plot with the numerical results and observe, according to the results obtained, it does comply with the accuracy specification indicated by the manufacturer in the respective user manual [5].
- The specifications [5] are shown in the following table:

Table 1. Triplett™ 60 NA, VMc-CD. Characteristics and specifications.

Range	15 [V]
Accuracy	±1.5% Full Scale
Sensitivity	Approximately20 [kΩ/[V]
Maximum input voltage	1000 [V]
Scale	0-15
Resolution	0.1 [V]
Mounting	Horizontally
Temperature calibration	25 [°C] ± 5*[°C]

*Commonly accepted.

Use as standard, a BK Precision ™ multimeter, model 5390, in its VMp-CD function, in the ranges of 5 and 50 [V], the specifications [6] are shown in the following table:

Table 2. BK Precision™, model 5390, VMp-CD. Characteristics and specifications.

Ranges	5 and 50[V]
Accuracy	±(0.025%R+2D)*, both ranges
Input impedance	11[MΩ] and 10[MΩ], respectively
Maximum input voltage	1100 [V]
D	0.0001 and 0.001[V], respectively
Resolution	100[μV] and 10[mV], respectively
Accuracy apply from	18 to 28 [°C]

*n%R+nD, means **n**% of **R**eading + **n** least significant **D**igits [6]

Validation of the accuracy requirements of the standard instrument [2]:

$$\frac{\text{AccuracyTriplett™VMc} - \text{CD}}{\text{AccurayBKPrecision™, bothrangesVMp} - \text{CD}} = \frac{1.5\%}{0.025\%} = 60\ \text{timesbestthanaccuracyTriplett™VMc} - \text{CD}$$

The points mentioned in II and III are considered. For the range of 15 [V], according to table 1, 10 readings are taken at the following points on the VMc-CD scale: 2.5, 5.0, 7.5, 10.0, 12.5 and 15 [V]. Table 3 shows the recorded readings:

Table 3. Record Readings

Points scale		2.5 [V]	5.0 [V]	7.5 [V]	10.0 [V]	12.5 [V]	15.0 [V]
Range VMp		5 [V]	50 [V]	50 [V]	50 [V]	50 [V]	50 [V]
Counter readings	1	2.5566	5.233	7.703	10.176	12.733	15.147
	2	2.5455	5.122	7.675	10.181	12.685	15.145
	3	2.5142	5.224	7.696	10.181	12.738	15.150
	4	2.5323	5.199	7.524	10.183	12.731	15.150
	5	2.5233	5.029	7.581	10.174	12.680	15.144
	6	2.5810	5.053	7.512	10.201	12.703	15.151
	7	2.5025	5.053	7.681	10.163	12.734	15.149
	8	2.5416	5.253	7.528	10.003	12.685	14.988
	9	2.5391	5.089	7.676	10.169	12.690	14.947
	10	2.5381	5.101	7.495	10.194	12.721	14.974

The permissible magnitude of the error is calculated as:

$$e_{\text{permissible}} = \pm\left(\frac{\text{Acuarancy\% (VMc)}}{100\%} * \text{RangeVMc}\right) \qquad (12)$$

$$e_{\text{permissible}} = \pm\left(\frac{1.5\%}{100\%} * 15\ [\text{V}]\right)$$

$$e_{\text{permissible}} = \pm 0.225\ [\text{V}]$$

Table 4 shows the results obtained by performing the respective calculations according to equations 2 to 11, indicated in III, with the data in tables: 1, 2 and 3, and in figure 3 the respective plot.

Table 4. Numerical results.

Points scale	e_k	$Uc(e_k)$	$e_k - Uc(e_k)$	$e_k + Uc(e_k)$
2.5	-0.03742	0.07025696	-0.107677	0.03283696
5	-0.1356	0.08523735	-0.2208374	-0.05036265
7.5	-0.1071	0.0864067	-0.1935067	-0.0206933
10	-0.1625	0.07555239	-0.2380524	-0.08694761
12.5	-0.21	0.06953733	-0.2795373	-0.1404627
15	-0.0945	0.0862296	-0.1807296	-0.0082704

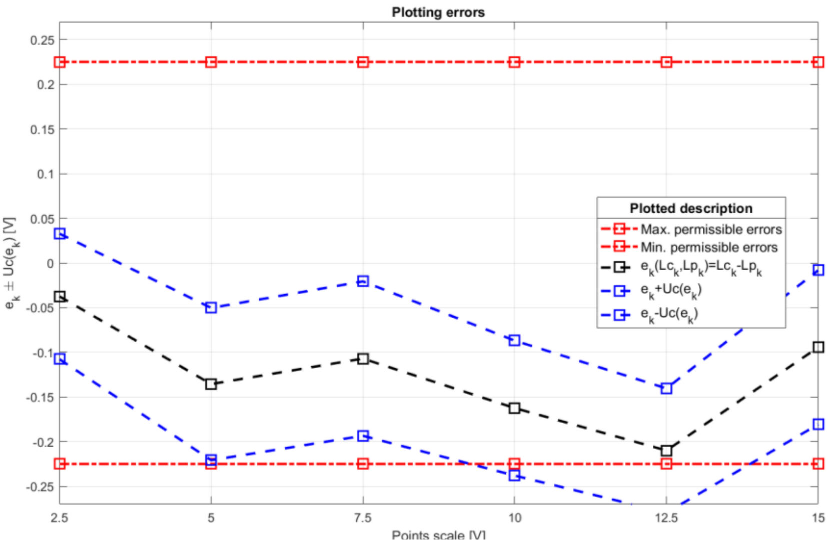


Figure 3. Plotting errors and its combined uncertainly

V. CONCLUSION

- In the data obtained in Table 4 and Figure 3, it is observed that the errors in the points of the scale corresponding to 10 [V] and 12.5 [V] exceed the maximum allowable absolute value of 0.225 [V], consequently it is considered that the VMc-CD in the range of 15 [V] is not reliable. For purposes where quality measurements are required, this instrument should not be used, and will eventually have to be repaired and adjusted and then calibrated in a certified laboratory.
- The verification of the errors in the measuring instruments is essential to carry out the quality measurement process, where the certainty of the determined values is required.
- The accuracy of the measuring instruments is the aptitude of the instrument that allows knowing the absolute permissible value of the errors that are detected when an analog measuring instrument is used.
- Error theory allows quantification of errors and their respective combined uncertainty.
- The environmental conditions influence the accuracy of the analog measuring instruments, these are indicated in the documents (manuals) provided by the manufacturer of the measuring instruments.
- The graphic presentation of the errors facilitates their analysis and allows observing, where appropriate, at which point of the scale the highest error values are found.

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