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Verification of Accuracy in Analog Ammeter

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--***ABSTRACT***--
This paper describes the procedure for verify the accuracy and the errors of measurements in an analog ammeter, including the calculation of the expanded 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 ammeter.
KEYWORDS;- *Accuracy, errors, uncertainty, ammeter, 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 influence 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].

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 [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.

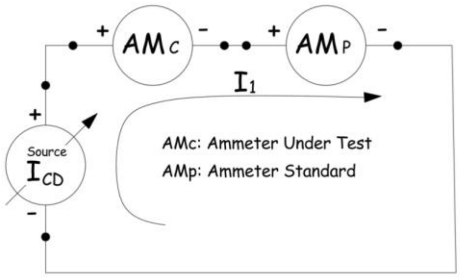

Figure 1. Electrical diagram connections.

III. PROCEDURE FOR THE DETERMINATION ERRORS IN 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 *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 electrical current 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:

$$e_k(Lc_k, Lp_k) = Lc_k - Lp_k \quad (1)$$

Donde:

e_k -error in the k mark of the scale of the ammeter under test.
Lc_k - instrument reading under test.
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 ammeter.
• The variability of the readings at each point k of the scale.
• The resolution of the ammeter under test.

Uncertainly Standard type

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, $\overline{Lp_k}$:

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

Where:

Lp_j - measurements on the k mark of the standard ammeter scale.

Experimental variance of readings, $s^2(Lp_k)$:

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

Estimated standard deviation, $s(Lp_k)$:

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

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

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

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]

$$U_B(AMc) = \frac{\frac{Resolution}{2}}{\sqrt{3}} \qquad (6)$$

Where:

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

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

$$U_B(AMp)_k = \frac{U_E(AMp)_k}{\sqrt{3}} \qquad (7)$$

Where:

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

The best estimation errors

The best estimate of the error in each scale mark on the analog ammeter under test is calculated as:

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

Where:

$\overline{e_k}$ mean of the errors in $\boldsymbol{k}$ point.
Lc_k value step measure in $\boldsymbol{k}$ point.
$\overline{Lp_k}$ mean measure ammeter standard in $\boldsymbol{k}$ point.

Combined uncertainly Standard

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

$$Uc^2(e_k) = C1^2U_B(AMc)^2 + C2^2U_A(\overline{Lp_k})^2 + C2^2U_B(AMp)_k{}^2 \qquad (9)$$

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:

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

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

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

Expanded uncertainly Standard

The k factor in equation 12 is determined by solving 13, and with this result, it is looked up in table 5 on page 48 [1].

$$U(e_k) = k(veff, N.C) * Uc(e_k) \qquad (12)$$

$$veff = \frac{Uc^4(e_k)}{\frac{U_C(AMc)^4}{8} + \frac{U_C(\overline{Lp_k})^4}{9} + \frac{U_C(AMp)_k{}^4}{8}} \qquad (13)$$

$N.C. = 95.45\%$

Finally, the result is expressed as:

$$e_k \pm U(e_k) \qquad (14)$$

IV. EXAMPLE CASE: TEST AND RESULTS

- Calculate the best variation of errors, including their combined uncertainty, for the 100 mA range of a Triplett ™ brand analog multimeter, model 60 NA, in the direct current ammeter (AM-CD) function.
- 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, *AMc-CD*. Characteristics and specifications.

Range	100 mA
Accuracy	±1.5% Full Scale
Scale	0-10
Resolution	0.2 mA
Mounting	Horizontally
Burden Voltage	600 mV
Temperature calibration	25 [°C] ± 5*[°C]

*Commonly accepted.

Use as standard, a BK Precision ™ multimeter, model 5390, AM-CD function, in the ranges 50 mA and 500 mA, the specifications [6] are shown in the following table:

Table 2. BK Precision™ 60, model 5390, *AMp-CD*. Characteristics and specifications.

Ranges	50 mA and 500 mA
Accuracy	±(0.05%R+2D)* and ±(0.2%R+2D), respectively
Max Burden Voltage	700 mV and 1.5 V, respectively

Resolution	0.001 mA and 0.01 mA, respectively
Counts	50000
Accuracy apply from	18 °C 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]:

$$\frac{Accuracy\ Triplett^{\text{TM}}\ AM-CD}{Accuray\ BK\ Precision^{\text{TM}}\ \ AM-CD,\ \ range\ 50\ mA}=\frac{1.5\%}{0.05\%}$$

$30\ times\ best\ than\ accuracy\ Triplett^{\text{TM}}\ AMc-CD$

$$\frac{Accuracy\ Triplett^{\text{TM}}\ AM-CD}{Accuray\ BK\ Precision^{\text{TM}}\ \ AM-CD,\ \ range\ 500\ mA}=\frac{1.5\%}{0.2\%}$$

$7.5\ times\ best\ than\ accuracy\ Triplett^{\text{TM}}\ AMc-CD$

The points mentioned in II and III are considered. For the range 100 mA, according to table 1, 10 readings are taken at the following points on the AMc-CD scale: 20, 40, 60, 80 and 100 mA. Table 3 shows the recorded readings:

Table 3. Record Readings, *AM_P-CD*

Points scale, *AMc-CD*		20 mA	40 mA	60 mA	80 mA	100 mA
Counter readings	1	19.727	40.142	60.21	80.51	99.75
	2	19.720	40.013	60.18	80.85	99.61
	3	19.712	39.896	60.07	80.64	99.68
	4	19.767	39.934	60.24	80.35	98.72
	5	19.757	40.162	60.33	80.38	99.79
	6	19.695	39.939	59.95	80.59	98.65
	7	19.722	39.916	59.93	80.29	98.94
	8	19.917	39.810	59.83	80.19	98.62
	9	19.831	39.555	59.74	79.90	98.78
	10	19.913	39.697	59.69	79.92	99.98

The permissible magnitude of the error is calculated as:

$$e_{permissible}=\pm\left(\frac{Acuarancy\%\ (AMc)}{100\%}*Range\ AMc\right) \qquad (15)$$

$$e_{permissible}=\pm\left(\frac{1.5\%}{100\%}*100\ mA\right)$$

$$e_{permissible}=\pm 1.5\ mA=|1.5\ mA|$$

Table 4 shows the results obtained by performing the respective calculations according to equations 2 to 14, indicated in III, with the data in tables: 1, 2 and 3, and in figure 3 the respective plot.

Table 4. Numerical results. Errors and Expanded Uncertainty

Points scale, mA	e_k, mA	$\pm\ U(e_k), mA$
20	0.224	0.143654
40	0.094	0.180336
60	-0.02	0.255847
80	-0.36	0.324751
100	0.75	0.476348

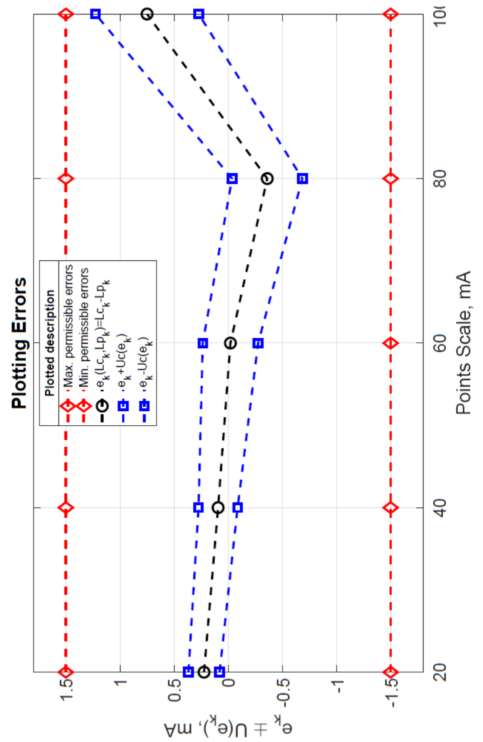

Figure 3. Plotting errors and expanded uncertainly

V. CONCLUSION

- In the data obtained in Table 4 and Figure 3, it is observed that the errors in all the points of the scale does not exceed the maximum allowable absolute value ±1.5 mA, consequently it is considered that the AMc-CD in the range 100 mA is reliable.
- 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.
- 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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