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Internal Ohmic Resistance in Alkaline Battery

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---*ABSTRACT*---

The experimental procedure to determine the magnitude of the internal ohmic resistance of a 1.5 V alkaline battery (ROIP) is documented, and the expanded uncertainty associated with the measurement procedure is calculated. The ROIP is determined using an indirect measurement method, which considers the implementation of the numerical method of least squares of first order, which achieves the linearization of a curve. The procedure was applied to three specimens of the same brand, model and type, for which the numerical and graphical results obtained are shown.

KEYWORDS; *Ohmic resistance, alkaline battery, measurement uncertainty, measurement, linearization*

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I. INTRODUCTION

1.5 V alkaline batteries are currently used to power certain portable domestic appliances and are even used in laboratory equipment and measuring instruments. Alkaline batteries are not rechargeable, however, they have the following advantages: higher electrical charge density, higher power, can power light loads for continuous use and have a longer life compared to carbon batteries.

The measurement of the internal ohmic resistance of a battery is not possible by conventional methods of measurement, instead indirect methods are employed, which involve measuring electrical parameters that are functionally related to the quantity of interest.

In the process of obtaining the magnitudes of the measurable parameters, there is a risk of causing irreversible damage to the battery, which would result in the loss of charge in the battery. The most serious damage occurs when a relatively large magnitude of electric current is demanded from the battery, and it is required a magnitude of current sufficient to cause an appreciable voltage drop in the internal resistance of the battery, and then its magnitude can be determined indirectly.

Thus, the need is established to employ suitable measurement methods that allow obtaining minimum current magnitudes, such that they do not damage the battery, but at the same time cause appreciable and reliable magnitudes of voltage drop in the internal resistance. [1, 2]

II. MEASURING METHOD

R is an relatively low resistance magnitude, so it is required to measure it with four terminals, two to measure the voltage drop, this is measured with a voltmeter ***VM*** and its respective internal resistance ***RVM***, ***VM*** is connected and disconnected with the push button ***PVM***, and two terminals to circulate a current through ***R***, a load resistor ***RC*** is used, which is connected and disconnected with the push button ***PRC***, it is important to keep the latter closed for very short times, only while the measurement is made in ***VM***. ***RC*** is variable in fixed steps of magnitudes such that the current flow is adequately limited so as not to damage the battery, but sufficient to cause a voltage drop in ***R*** that is sufficient and reliable. The ***RC*** magnitudes must be known accurately, so they are pre-measured with a Wheatstone bridge.

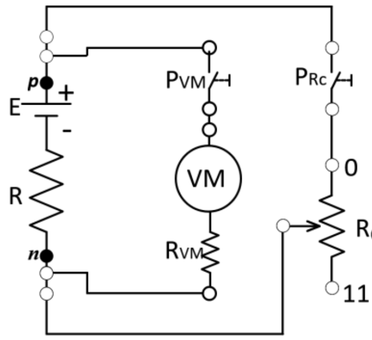

Figure 1. Electrical circuit used to measure *ROIB*.

III. DETERMINATION OF THE MEASUREMENT RESULT

The result of the measurement of the internal ohmic resistance of the battery is expressed as:

$$\boldsymbol{R} \pm \boldsymbol{U}(\boldsymbol{R})$$

Where:
R, best estimate of the internal ohmic resistance of the battery, Ω
U(R), expanded uncertainty measurement ***R***, Ω

Eq. 1 corresponds to the mathematical definition for the determination of the best estimate of ***R***, the procedure for the determination of Eq. 1 is shown [1].

$$R(a, b, R_{VM}) = \frac{b * R_{VM}}{a * R_{VM} - b} \dots .(eq. 1)$$

Where:
$\boldsymbol{R_{VM}}$, internal resistance of the voltmeter ***VM***
a and ***b***, coefficients of the fitted line: $\frac{\mathbf{1}}{\boldsymbol{VM}}\left(\frac{\mathbf{1}}{\boldsymbol{Rc}}\right) = \boldsymbol{b} * \frac{\mathbf{1}}{\boldsymbol{Rc}} + \boldsymbol{a}$

The coefficients ***a*** and ***b*** of the fitted line are determined using the numerical method of least squares of first order [3], with which the scattered points obtained with the voltage measurements with the ***VM*** and values of ***Rc*** measured by the Wheatstone bridge are linearized. This in synthesis is done by solving the following system of linear equations:

$$\begin{bmatrix} n & \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x_i^2 \end{bmatrix} * \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_i * y_i \end{bmatrix}, where\text{: } x_i = \frac{1}{VM_i};\ y_i = \frac{1}{Rc_i}$$

In eq. 1, it is observed that the sources of uncertainty are:

- The uncertainty with respect to the determination of the coefficients ***a*** and ***b***, these obtained by the numerical method of least error squares.
- The uncertainty regarding the magnitude of $\boldsymbol{R_{VM}}$.

Uncertainty regarding the type A evaluation of the standard uncertainty:

- In the procedure used no repeated values are taken on the same point, which precludes the type A evaluation of the standard uncertainty for ***a***, ***b*** and $\boldsymbol{R_{VM}}$.

Regarding the type B evaluation of the standard uncertainty:

- For the parameters of the fitted line a standard probability distribution is considered, so:
  - $U_B(a) = S_{ma}$, *average standard deviation* ***a***
  - $U_B(b) = S_{mb}$, *average standard deviation* ***b***

Where:

$$S_{my}^2 = \frac{S_y}{\sqrt{n}} \qquad S_y = \sqrt{\frac{1}{n-2} * \sum_1^n (y_i - (a + b * x_i))^2}$$

$$S_{ma}^2 = \frac{S_{my}^2 \sum x_i^2}{n \sum x_i^2 - (\sum x_i)^2} \qquad S_{mb}^2 = \frac{n\, S_{my}^2}{n \sum x_i^2 - (\sum x_i)^2}$$

$$S_{ma} = \sqrt{S_{ma}^2} \qquad S_{mb} = \sqrt{S_{mb}^2}$$

- The instrument manuals specify the magnitude of $\boldsymbol{R_{VM}}$, this is specified as a symmetric interval of maximum values, if this is a probability distribution of the uniform type with mean value equal to zero:
  - $U_B(R_{VM}) = \frac{U_E(R_{VM})}{\sqrt{3}}$, $U_E(R_{VM}) = 1\% * R_{VM}$

For the determination of the combined standard uncertainty:

$$U_C^2(R) = C_1^2 * U_B^2(R_{VM}) + C_2^2 * U_B^2(a) + C_3^2 * U_B^2(b)$$

Where:

$$C_1 = \frac{\partial R}{\partial R_{VM}} = \frac{b^2}{(a * R_{VM} - b)^2}$$

$$C_2 = \frac{\partial R}{\partial a} = \frac{b * R_{VM}^2}{(a * R_{VM} - b)^2}$$

$$C_3 = \frac{\partial R}{\partial b} = \frac{a * R_{VM}^2}{(a * R_{VM} - b)^2}$$

Thus, the combined uncertainty:

$$U_C(R) = \sqrt{U_C^2(R)}$$

Finally, the expanded uncertainty:

$$U(R) = k * U_C(R)$$

Considering a certain level 95.45%, and a coverage factor k=2, [1]:

$$U(R) = 2 * U_C(R)$$

IV. MEASUREMENTS

The load resistance ***Rc*** shown in Figure 1, was measured with a Wheatstone bridge, figure 2 shows the connection, Table 1 shows the results:

Figure 2. ***Rc*** measurement

Step	M	Rs	***Rc***, Ω
10	0.001	9993	9.993
9	0.001	8998	8.998
8	0.001	8002	8.002
7	0.001	7007	7.007
6	0.001	6005	6.005
5	0.001	5010	5.010

Table 1. ***Rc*** results readings

Figure 3 shows the connection, according to figure 1, of the measurement system, a thermometer is added to verify that the temperature is appropriate.

Figure 3. Measuring system

The measurement procedure was performed with three 1.5 V alkaline batteries (same brand) size C, the records are shown in Table 2. Each measured voltage corresponds to a resistance value of ***Rc***

Battery: DRTC_01

i	***Rc***, Ω	VM, V	TM, °C
1	No load	1.5490	21.4
2	9.993	1.4297	21.4
3	8.998	1.4224	21.5
4	8.002	1.4149	21.5
5	7.007	1.4026	21.5
6	6.005	1.3889	21.5
7	5.010	1.3660	21.4

Battery: DRTC_02

i	***Rc***, Ω	VM, V	TM, °C
1	No load	1.5582	21.5
2	9.993	1.4661	21.5
3	8.998	1.4643	21.4
4	8.002	1.4609	21.4
5	7.007	1.4504	21.4
6	6.005	1.4418	21.4
7	5.010	1.4310	21.5

Battery: DRTC_03

i	***Rc***, Ω	VM, V	TM, °C
1	No load	1.5620	21.3
2	9.993	1.4541	21.4
3	8.998	1.4507	21.5
4	8.002	1.4421	21.3
5	7.007	1.4342	21.4
6	6.005	1.4214	21.3
7	5.010	1.4055	21.3

Table 2. Records of measured voltages and temperature

V. RESULTS

The procedure was used to determine the ***RIOB*** of three 1.5 V alkaline batteries, size "C": *DRTC_01*, *DRTC_02* and *DRTC_03*, the records of the measurements are shown in table 2.

The compute were performed with an *APP* developed in *Matlab*™ [4], this *APP* reads the measurements (table 2) from a text file, performs the respective calculations indicated in *III*, and displays the numerical and graphical results, in figures 4, 5 and 6 the results for the three measured batteries are shown.

Figure 4 shows the numerical and graphical results for the battery *DRTC_01*, it is observed that the best estimate magnitude of ***RIOB*** is 0.663 Ω, with an expanded uncertainty ***U(R)***: 0.035 Ω, determined with a certain level: 95.45% and k=2. This indicates that the true value of ***RIOB*** should be in the value interval: [0.628 to 0.698] Ω.

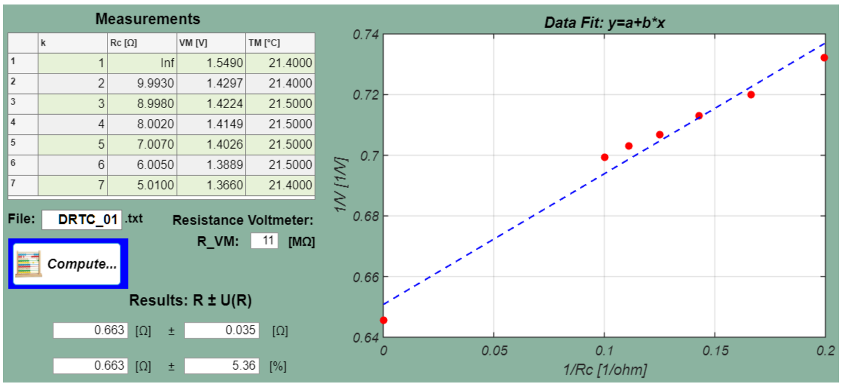

Figure 4. Numerical and graphical results for Battery *DRTC_01*

Figure 5 shows the numerical and graphical results for the battery *DRTC_02*, it is observed that the best estimate magnitude of ***RIOB*** is 0.444 Ω, with an expanded uncertainty ***U(R)***: 0.037 Ω, determined with a certain level: 95.45% and k=2. This indicates that the true value of ***RIOB*** should be in the value interval: [0.407 to 0.481] Ω.

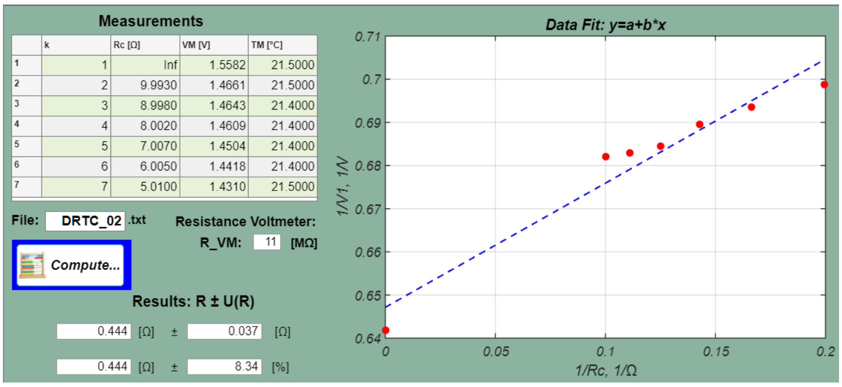

Figure 5. Numerical and graphical results for Battery *DRTC_02*

Figure 6 shows the numerical and graphical results for the battery *DRTC_03*, it is observed that the best estimate magnitude of ***RIOB*** is 0.553 Ω, with an expanded uncertainty ***U(R)*** of 0.039 Ω, determined with a certain level: 95.45% and k=2. This indicates that the true value of ***RIOB*** should be in the value interval: [0.514 to 0.592] Ω.

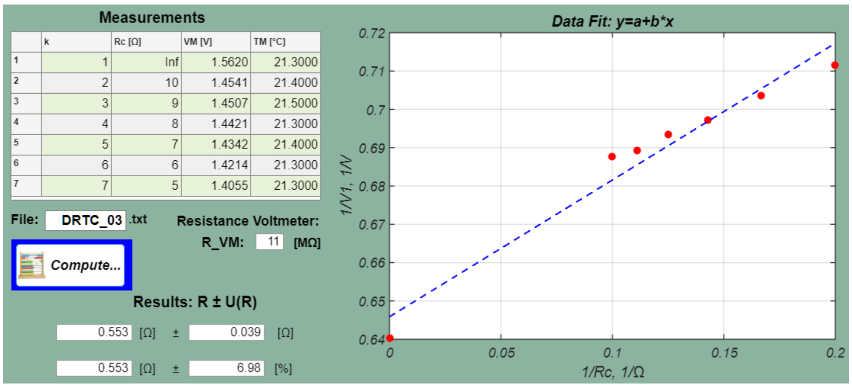

Figure 6. Numerical and graphical results for Battery *DRTC_03*

VI. CONCLUSIONS

- The procedure proposed in [1] is adequate for the proper determination of the *RIOB*.
- From the results for the three alkaline batteries, it can be indicated that the average *RIOB* is 0.553 Ω.
- The largest expanded uncertainty is 6.98%, even this result is appropriate for the intended purposes of the results.
- Computer programming is relevant and simplifies the numerical and graphical procedures.
- The application of the numerical method of least error squares, order 1, allowed to successfully perform the linearization of the scattered data in figure 4, 5 and 6.
- The determination of the expanded uncertainty allows obtaining more reliable results.

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