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# OHMIC Resistance Measurement

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***ABSTRACT***
*The procedure for measuring relatively high ohmic resistance (RHR) is shown. The indirect method is used, which allows determining the best estimate of the magnitude of an ohmic resistance. This procedure is an alternative to make an exact estimate of the magnitude of a resistance. greater than 10 Ω. Starting from Ohm's law, the mathematical model is developed that considers the readings of voltmeter, ammeter and thermometer; this model implies correction for temperature at 20 °C of the measured magnitude. In addition, an experimental example is shown, the magnitude obtained is compared against the measurement made with a Wheatstone bridge.*

***KEYWORDS;-*** *Ohmic resistance, indirect method, Ohm's law, experimental, Wheatstone Bridge*.

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## I. INTRODUCTION

The measurement of the magnitudes of the electrical parameters that characterize the elements and devices that are part, in general, of electrical circuits, is a complex task, since it aims to know the numerical magnitude that "truly" represents the parameter in question. [1], this is essential for certain device design procedures, equipment diagnosis, mathematical modeling, digital or analog simulation, etc.

In particular, the quality of the measurement of an ohmic resistance ***R*** requires specialized instruments. Depending on the magnitude of ***R***, different instruments are used. Regarding its magnitude ***R***, it can be considered relatively low (***RLR***) for magnitudes of 10 Ω or less, and relatively high (***RHR***) when its value is greater than 10 Ω [2]. Thus, for example, to measure ***RHR*** with good accuracy, instruments based on the Wheatstone bridge configuration with two terminals are used, or even for extremely high ***R***, megohmmeters are used.

This document shows the procedure to determine the magnitude of ***R*** with the minimum possible error. The procedure involves the use of three instruments: voltmeter, ammeter and thermometer, and their respective user manuals, from which the necessary characteristics and specifications are obtained; this as an alternative for when you do not have a Wheatstone bridge.

## II. MEASURES ERRORS

It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those that come from systematic effects, such as the components associated with corrections and reference standards, contribute to the dispersion of the magnitude of the error.

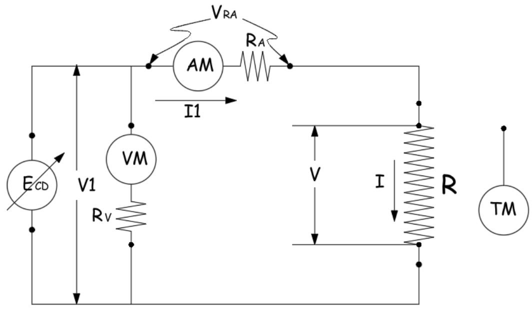
While the exact values of the contributions to the error of a measurement result are unknown and cannot be known, the uncertainties associated with the random and systematic effects that give rise to the error can be evaluated. The uncertainty of a measurement result is not necessarily an indication of the feasibility of the measurement result being close to the value of the measurand; it simply implies an estimate of the feasibility of closeness with the best value that is consistent with the knowledge currently available [1,3].

Measurement uncertainty is therefore a way of expressing the fact that, for a given measurand and its measurement result, there is not a single value, but an infinite number of values dispersed around the result that are consistent with all measurements. observations, data and knowledge that are available about the physical world, and that with different degrees of credibility can be attributed to the measurand [1,3].

## III. OHMIC RESISTANCE MEASUREMENT

Figure 1 shows the electrical circuit to measure the ohmic resistanc***e RHR***, this is based on the indirect measurement method, in which the value of the magnitude to be measured is obtained by measuring the magnitudes of other functionally related parameters. with the magnitude of interest [2].

Additionally, a ***TM*** thermometer is integrated to measure the ambient temperature.




Where:

| | |
|---|---|
| *$E_{CD}$, $V_1$ ,* | Voltage Source CD |
| *AM ,* | Ammeter |
| *VM ,* | Voltmeter |
| *TM ,* | Thermometer |
| *$R_A$ ,* | Internal ammeter resistance |
| *$V_{RA}$ ,* | Voltage drop in ***$R_A$*** |
| *$R_V$ ,* | Internal voltmeter resistance |
| *I1 ,* | Current through ***AM*** |
| *I ,* | Current through ***R*** |
| *V ,* | Voltage drop in ***R*** |

**Figure 1**. Electrical circuit for measure ***RHR***

**Development of the mathematical model**

The mathematical modeling for the determination of ***R*** is based on Ohm's law (1):

$$R = \frac{V}{I} \tag{1}$$

If the internal resistance ***$R_V$*** of the voltmeter is infinite, the internal resistance ***$R_A$*** of the ammeter is zero and the resistance of the conductors is zero, then equation 1 is fulfilled. When it is used, a systematic error is generated due to the approximation and simplification of mathematical expressions, since the assumption regarding the internal resistances of instruments and conductors are not satisfied in practice [2].

Making the appropriate considerations and corrections, it is possible to use the electrical circuit of figure 1. Thus, from figure 1 and equation 1, we have that the current ***I*** that circulates through ***R*** is the same as that measured by the ***AM***, that is:

$$I = I1 \tag{2}$$

The voltage measured by the ***VM*** is the same as that of the ***$E_{CD}$*** source, which is indicated as ***V1***:

$$V1 = V_{RA} + V$$
$$V = V1 - V_{RA}$$
$$V_{RA} = I1 * R_A$$
$$V = V1 - I1 * R_A \tag{3}$$

Replacing (2) and (3) in (1):

$$R = \frac{V1}{I1} - R_A \tag{4}$$

For cases where the magnitude of the ohmic resistance of ***R*** is affected by the ambient temperature, a factor ***α20*** characteristic for each material is added.

Equation 5 determines the best estimate of the magnitude of ***RHR*** at 20 °C.

$$R_{20} = \left(\frac{V1}{I1} - R_A\right) * \left(1 + \alpha_{20}(20 - t)\right) \tag{5}$$

Where:

| | |
|---|---|
| $R_{20}$ | Best value ***R*** to 20 °C. |
| V1 | Mean voltage measurement. |
| I1 | Mean current measurement. |
| $R_A$ | Internal ammeter resistance. |
| $\alpha_{20}$ | Material coefficient. |
| t | Mean temperature measurement. |

**General considerations**

- Electrical characteristics of the instruments
  - Internal resistance of the voltmeter ***$R_V$***, it is recommended equal to or greater than 10 MΩ.
  - Internal resistance of the ammeter RA, ideally small.
  - Determine from the datasheet the magnitude of the nominal current of resistor ***R***.
  - Select the appropriate range on the ammeter, this must be appropriate to the nominal current of ***R***.

- For the voltmeter, an appropriate range is required to measure the voltage drop across the terminals of ***R***.
- It is recommended that the resolution of the thermometer be at least 0.1 °C.

- Assembly and connection of instruments (figure 1)
  - Ensure that the magnitude of the current in the variable voltage source $E_{CD}$ is sufficient to provide at least the rated current of ***R***.
  - Place the instruments in the position (vertical or horizontal) indicated by the manufacturers.
  - Place the thermometer close to resistor ***R***.
  - Allow thermal conditioning of the instruments, for this it is necessary to adjust the $E_{CD}$ source until the ammeter indicates its maximum value, according to the selected range, and maintain this condition for at least half an hour.

Determine the best magnitude of the ohmic resistance (at 20 °C) of an inductor: 1.24 H, 5000 turns, built with #22 copper wire.

In figure 2, you can see the image that shows the physical arrangement of the measuring instruments, the power supply and the inductor.


**Figure 2**. Assembly and connection of measuring instruments and other devices

The specifications of the ***VM*** voltmeter are shown in table 1 [4], in table 2, the specifications of the ***AM*** ammeter [5]:

**Table 1.** BK Precision™, model 5390, voltmeter-*CD*. Characteristics and specifications

| | |
|---|---|
| Range | 50 V |
| Accuracy | ±(0.025%R+2D)* |
| Counts | 50000 |
| Input impedance, Rv | 10 MΩ |
| D | 0.001 V |
| Resolution | 1 mV |
| Mounting | Not indicated |
| Accuracy apply from | 18 °C to 28 °C |

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

**Table 2.** Triplett™ 60 NA, ammeter-*CD*. Characteristics and specifications

| | |
|---|---|
| Range | 50 mA |
| Accuracy | ±1.5% Full Scale |
| Voltage Burden | 300 mV |
| $R_A$ | 6 Ω |
| Scale | 0-50 |
| Resolution | 0.1 mA |
| Mounting | Horizontally |
| Temperature calibration | 25 °C ± 5 °C |

Table 3 shows the specifications of the thermometer ***TM*** [6].

**Table 3.** AEMC™ CA865. Characteristics and specifications.

| | |
|---|---|
| Range | -50 to 100 [°C] |
| Accuracy meter | ± 0.5 [°C] plus RTD |
| Accuracy RTD | ± 1.0 [°C] |
| Resolution | ± 0.1 [°C] |

To consider the variability in the readings in the instruments, ten readings are taken, each set includes a voltmeter reading ***VM***, an ammeter reading ***AM*** and a thermometer reading ***TM***. In each set of readings the source is adjusted to make the indicated ***AM*** current approximately half its full range. The magnitudes of the instruments, ***VM*** and ***TM***, are recorded when the current in ***AM*** is at full range.

The reading record is shown in table 4.

**Table 4.** Readings

| ***k*** | ***VM*** ,V | ***AM,*** mA | ***TM,*** °C |
|---|---|---|---|
| 1 | 11.694 | 50 | 19.6 |
| 2 | 11.691 | 50 | 19.7 |
| 3 | 11.692 | 50 | 19.8 |
| 4 | 11.696 | 50 | 19.8 |
| 5 | 11.690 | 50 | 19.7 |
| 6 | 11.688 | 50 | 19.8 |
| 7 | 11.693 | 50 | 19.7 |
| 8 | 11.694 | 50 | 19.7 |
| 9 | 11.692 | 50 | 19.7 |
| 10 | 11.689 | 50 | 19.7 |

**Calculations**

In table 5, the values required in (5) are indicated, these are obtained from the averages of the readings recorded in table 4. The resistance ***RA*** is also indicated (table 1), as well as the value of ***α20*** for copper [2].

**Table 5**. Mean of the readings and other necessary quantities

| ***V,*** V | ***I1***, mA | $R_A$, MΩ | ***t***, °C | $\alpha_{20}$, 1/°C |
|---|---|---|---|---|
| 11.692 | 50 | 6 | 19.7 | 0.00393 |

Substituting the values from table 5 in (5):

$$R_{20} = \left(\frac{11.692\ V}{50\ mA} - 6\ \Omega\right) * \left(1 + 0.00393\ \frac{1}{°C} * (20 - 19.7)\ °C\right)$$

Finally, the best estimate of the magnitude of the ohmic resistance at 20 °C of the inductor is:

$$R_{20} = 228.109\ \Omega$$

In order to validate the procedure and its respective result, the ohmic resistance of the inductor was measured with a Wheatstone Bridge ***(PW)*** -figure 3-, the result of the measurement is indicated in table 6, as well as the calculation of the relative percentage error, taking the ***PW*** reading as a reference -table 7-:

**Figure 3.** Measurement, ***PW***

**Table 6**. Readings, ***PW***

| ***R_PW***, Ω | ***TM***, °C |
|---|---|
| 227.3 | 19.1 |

$$R_{20}\_PW = 227.3\ \Omega\left(1 + 0.00393\ \frac{1}{°C}(20 - 19.1)°C\right)$$

$$R_{20}\_PW = 228.104\ \Omega$$

**Table 7.** Comparison

| $R_{20}$***_PW***, Ω | $R_{20}$, Ω | er% |
|---|---|---|
| 228.104 | 228.109 | 0.0022 |

## IV. CONCLUSION

- The mathematical model (5) is appropriate as indicated by the results in table 7.
- The procedure described is appropriate for measuring ohmic resistance ***RHR*** when a Wheatstone bridge is not available.
- It is essential to know the characteristics and specifications of the measuring instruments and other devices used.

- During measurement processes, in general, errors always occur, which cannot be avoided.
- The knowledge and characterization of the sources of error allows for the development of more appropriate mathematical models that minimize or control the effects of errors in the measurement processes.

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