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Low Ohmic Resistance Measurement

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ABSTRACT

The procedure for the measurement of low ohmic resistance is developed;the indirect method is used, which allows to determine the best estimate of the magnitude of a low ohmic resistance without the need for a Kelvin bridge. Starting from Ohm's law and the four-terminal configuration of a resistor, the mathematical model that involves the readings of a voltmeter, an ammeter and a thermometer is developed; this model implies the correction by temperature at 20 [°C] of the measured magnitude. In addition, an experimental example and the numerical results obtained are shown.

Keywords: *Low ohmic resistance, indirect method, Ohm's law, Kelvin Bridge, four terminals.*

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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 the electrical circuits, is a complex task, since it seeks to know the numerical magnitude that “really” represents the parameter in question [1], this is essential for certain device design procedures, equipment diagnostics, mathematical modeling, digital or analog simulation, etc.

In particular, the measurement of ohmic resistance quality ***R*** requires specialized instruments. Depending on the magnitude of ***R***, different instruments are used. Regarding ***R***magnitude, it can be considered as low for magnitudes of 10 [Ω] or less, and high when its value is greater than 10 [Ω] [2]. Thus, for example, to measure low ***R***, instruments based on the configuration of the Kelvin Bridge with four terminals or micro-ohms are used; For the measurement of high ***R***, instruments based on the Wheatstone bridge configuration are used, or even for extremely high ***R***, megohmmeters are used.

This paper 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, where the necessary characteristics and specifications are obtained; this is done as an alternative when it doesn't have a Kelvin bridge.

II. ERRORS IN THE MEASUREMENT PROCESS

In general, during the measurement processes there are deficiencies, which give rise to the generation of errors and uncertainty in the measurement result. The knowledge of the errors during the measurement is very important to estimate the reliability of the results.

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

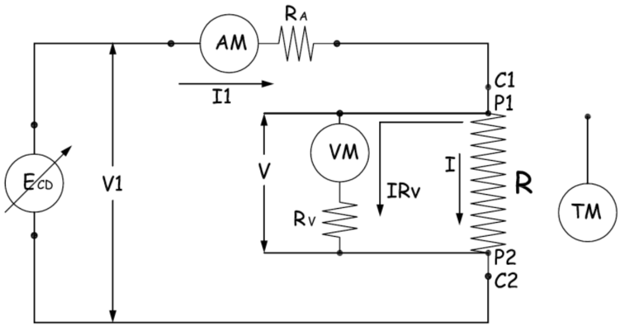
While the exact values of the contributions to the error of a measurement result are unknown and cannot be known, the uncertainties associated with the random and systematic effects that give rise to the error can be evaluated. The uncertainty of the result of a measurement is not necessarily an indication of the feasibility that the result of the measurement is close to the value of the measurand; it simply implies an estimate of the feasibility of proximity 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 scattered around the result that are consistent with all observations, data and knowledge of the physical world, and that with varying degrees of credibility can be attributed to the measurand [1, 3].

III. LOW OHMIC RESISTANCE MEASUREMENT

In figure 1, the electrical circuit to measure the low ohmic resistance ***R*** is shown; 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 related parameters with the magnitude of interest [2].

To measure the ohmic resistance ***R*** in Figure 1, a ***VM*** voltmeter and an ***AM*** ammeter are used. If the voltage drop ***V*** at terminals of a resistor ***R***, and the current ***I***, which passes through it are measured as: ***P1-P2*** and ***C1-C2***, respectively, the magnitude of the resistance ***R*** can be determined using the ohm's law, considering that instruments are ideal [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
R_v	Internal voltmeter resistance
I1	Current through AM
I	Current through ***R***
IRv	Current through VM
C1-C2	Current measurement
P1-P2	Voltage measurement

Figure 1. Electrical circuit to measure low resistance.

Development of the mathematical model

The mathematical modeling for ***R*** determination is based on ohm'slaw (ec. 1):

$$R = \frac{V}{I} = \frac{VM}{AM}[\Omega] \qquad (1)$$

If the internal resistance ***Rv*** 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 this is used a systematic error is generated due to the approximation and simplification of mathematical expressions, since the assumption regarding the internal resistance of the instruments and the conductors is 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, the ***IRv*** current flowing through ***VM*** is negligible, due to the high value of its internal resistance ***Rv***(usually for digital instruments is indicated as mega or even giga ohm) consequently the error generated by the voltage drop in ***VM*** is also negligible, this is because ***VM*** is directly connected in ***P1-P2*** to the terminals of **R**, which makes it unnecessary to measure the voltage drops in the conductors, so Equation 1 can be indicated as (Eq. 2):

$$R = \frac{V}{I} \Big| I = I_1 - I_v = \frac{V}{I_1 - I} = \frac{V}{I_1 - \frac{V}{R_V}} = \frac{R_V V}{I_1 R_V - V} \qquad (2)$$

Cases where the magnitude of the ohmic resistance of the resistor ***R*** is affected by the ambient temperature, a characteristic $\boldsymbol{\alpha}_{20}$ factor is added for each material.Equation 3 determines the best estimate of ***R*** at 20 [°C].

$$R_{20} = \left(\frac{R_V * V}{I_1 * R_V - V}\right) * \left(1 + \alpha_{20}(20 - t)\right) \qquad (3)$$

Where:

R_{20}	Best value ***R*** to 20 [°C].
Rv	Internal voltmeter resistance.
V	Average voltmeter readings.
I_1	Average ammeter readings.
α_{20}	Materialcoefficient.
t	Average thermometer readings.

General considerations [2]:

- *Electrical characteristics of the instruments*
    - Internal resistance of the voltmeter, ***Rv*** very high, is recommended equal to or greater than 1 [GΩ].
    - Internal ammeter resistance, R_A very low, recommended equal to or less than 1 [Ω].
    - Determine from the data plate, the magnitude of the nominal current of the resistor ***R***.
    - Select the appropriate range in the ammeter, it should be appropriate to the nominal current of ***R***.
    - For the voltmeter, an appropriate range is required to measure the voltage drop at terminals ***P1-P2*** of ***R***, usually in milli-volts.
    - It is recommended that the resolution of the thermometer be at least 0.1 [° C].

- *Assembly and connection of instruments (figure 1):*
    - Make sure that the magnitude of the current in the variable voltage source $E_{CD}$is sufficient to provide at least the nominal current of ***R***.
    - Place the instruments in the position (vertical or horizontal) indicated by the manufacturers.
    - Place the thermometer near resistor ***R***.
    - Make sure that the voltmeter terminals are in the connection position ***P1-P2***.
    - Make surethe ammeter terminals are in the ***C1-C2*** connection position.
    - Allow the thermal conditioning of the instruments.For this it is necessary to adjust the E_{CD}source until the ammeter shows its maximum value, according to the selected range, and maintain this condition for at least half an hour.

IV. TEST CASE AND RESULTS

Determine the best estimate of the magnitude of the ohmic resistance at 20 [° C], of the low-voltage coil of a single-phase transformer, with transformation ratio 127 [VAC] to 9.8 [VCA], both coils are constructed with wire copper.

Figure 2 shows the physical connection of the measuring instruments, the power supply and the single-phase transformer.

Figura 2. Assembly and connection of measuring instruments and other devices.

The specifications of the ***VM*** voltmeter are shown in table 1 [4]:

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

Range	500[mV]
Accuracy	±(0.025%R+2D)*
Input impedance	1 [GΩ]
D	0.01[mV]
Resolution	10[microV]
Mounting	Not indicated
Accuracy apply from	18 to 28 [°C]

*n%R+nD, means ***n***% of ***R***eading + ***n*** least significant ***D***igits [4]

Table 2 shows the specifications of the ***AM*** ammeter [5]:

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

Range	500 [mA]
Accuracy	±1.5% Full Scale
Voltage Burden	500 [mV]
R_A	1 [Ω]
Scale	0-50
Resolution	1 [mA]
Mounting	Horizontally
Temperature calibration	25 [°C] ± 5*[°C]

*Commonlyaccepted.

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

In order to consider the variability in the readings in the instruments, ten sets of readings are taken, each set includes a reading of the ***VM*** voltmeter, a reading of the ***AM*** ammeter and a reading of the ***TM*** thermometer. Between each set of readings the source is adjusted to make the current indicated in ***AM*** approximately half of its full range. The magnitudes of the instruments are recorded when the current in ***AM*** is at full range.The record of the readings is shown in table 4:

Table 4. RecordReadings.

k	***VM*** [mV]	***AM*** [mA]	***TM*** [°C]
1	32.09	500	21.3
2	31.97	500	21.4
3	31.99	500	21.4
4	31.94	500	21.4
5	32.06	500	21.4
6	31.9	500	21.5
7	31.93	500	21.5
8	31.94	500	21.5
9	31.91	500	21.5
10	31.89	500	21.5

Calculations

In table 5, the values required in equation 3 are indicated; these are obtained from the averages of the readings recorded in table 4. The resistance ***Rv*** (table 1) is also indicated, as well as the value of α_{20} for copper [2].

Tabla 5. Average readings and other necessary values.

V [mV]	$\boldsymbol{I_1}$ [mA]	***Rv*** [GΩ]	***t*** [°C]	$\boldsymbol{\alpha_{20}}$ [1/°C]
31.96	500	1	21.4	0.00393

Substituting the values in table 5, in equation 3:

$$R_{20} = \left(\frac{R_V * V}{I_1 * R_V - V}\right) * \left(1 + \alpha_{20} * (20 - t)\right)$$

$$R_{20} = \left(\frac{1\,[G\Omega] * 31.96[mV]}{500\,[mA] * 1[G\Omega] - 31.96[mV]}\right) * \left(1 + 0.00393\left[\frac{1}{°C}\right] * (20 - 21.4\,[°C])\right)$$

Finally, the best estimate of the magnitude of the ohmic resistance at 20 [° C] of the low-voltage coil of the single-phase transformer is:

$$R_{20} = 0.063568[\Omega] = 63.568\,[m\Omega]$$

In order to validate the procedure and its respective result, the ohmic resistance of the transformer coil with a Kelvin Bridge (R20 PK) was measured; the measurement result is indicated in Table 6, as well as the calculation of the percentage relative error, taking as reference the reading of the Kelvin Bridge:

Tabla 6. Validationofresults.

R_{20}***PK*** [mΩ]	R_{20} [mΩ]	er%
64.15	63.568	0.91

V. CONCLUSIONS

- The determination of the magnitude of low ohmic resistance is possible with the use of the indirect measurement method.
- The procedure described is appropriate for measuring low ohmic resistance when a Kelvin Bridge is not available.
- The mathematical model (ec. 3) is appropriate as indicated in table 6.
- It is essential to know the characteristics and specifications of the measuring instruments and other devices usedfor the calculation of resistance by this method.
- The knowledge and characterization of the sources of error, allows developing more appropriate mathematical models that minimize or control the effects of errors.

REFERENCES

[1]. Cedeño Aguilar, Benjamín. “Metrología Eléctrica”, Capítulo 1, E.S.I.M.E.-Zacatenco del IPN., México D.F. 2003. 620 pp.
[2]. Cedeño Aguilar, Benjamín. “Medición de una Resistencia Óhmica. Método Indirecto”, E.S.I.M.E.-Zacatenco del IPN., México D.F. 2004.
[3]. Ismael Castelazo Sinencio, “Uso de la distribución t en la estimación de la incertidumbre de la medición”, CENAM, El Marqués, Qro-, México, 2002.
[4]. Triplett™ 60 NA, “User manual”, Triplett Corporation, Bluffton, Ohio, EE. UU., 45817.
[5]. BK Precision™, “Instruction manual for models 5360, 370, 5380, 5390”,6470 W, Cortland St, Chicago, IL 60707.
[6]. AEMC™ Instruments, “Manual de Instrucciones: CA865”, 05/04 99-MAN 100243 v3, 15 Faraday Drive, Dover, NH 03820 USA.
[7]. American National Standars. Requirements for electrical analog indicating instruments, ANSI C39.1-1981. United States of America, New York: American National Standards Institute, January 1992.
[8]. MX-CH-110-1-1993-SCFI: “Instrumentos de medición de indicación analógica para magnitudes eléctricas - términos y definiciones.
[9]. NMX-CH-131-2-1994-SCFI: “Instrumentos de medición - instrumentos de iniciación digital para magnitudes eléctricas-especificaciones y métodos de prueba.
[10]. NMX-CH-131-1-1993-SCFI:“Instrumentos de medición - instrumentos de indicación digital para magnitudes eléctricas - términos y definiciones.

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