Modified Wheatstone bridge implementation at Inmetro

M V V Pinto[1] , R V F Ventura [1], L V S Costa [1], R R Pontes [1]

[1] Instituto Nacional de Metrologia, Qualidade e Tecnologia

E-mail: mvviegas@inmetro.gov.br

Abstract: The implementation of a measurement system for measuring high resistance is described. The system evaluation is reported throughout the text in conjunction with the comparison of the results obtained by the proposed system and the actual measurement system.

Keywords: Modified Wheatstone Bridge, High Resistance, Null Detection

1. INTRODUCTION

Measurement systems using the modified Wheatstone bridge allow the calibration of high value resistors and can reach values of the order of 10 PΩ [1].

Similar systems use null detection by current, the implemented system allows null detection also by voltage. Systems like this are used by several national metrology institutes such as CENAM, VSL, NIST and PTB.

The need to expand the service offering for calibration of high value resistors, besides obtaining an alternative to the commercial system currently used, motivated Inmetro to develop a similar system.

2. MEASUREMENT PRINCIPLE

A modified Wheatstone bridge system replaces two bridge resistors by high stability DC voltage sources, usually low impedance output calibrators. The other two bridge arms are formed by the reference resistor and the resistor to be calibrated. The system is mounted with two calibrators on two arms of the bridge, allowing a wide range of voltages and ratios. For null detection, an electrometer with a resolution of 100 aA or a multimeter with a resolution of 10 nV is used.

A significant advantage of this approach is that very low uncertainties can be obtained if the applied voltages can be calibrated with good accuracy. The leakage effects are small, because the measuring point of the system is balanced for zero volt [2]. For measurements up to 100 GΩ, the null detector can be a nanovoltmeter or an electrometer, and similar results are obtained for both null detection methods [3]. For larger resistance values, the null detection by current measurement method must be used since the value of Rs has the same order of magnitude of the input impedance of the nanovoltmeter. Figure 1 shows the simplified diagram of the system.

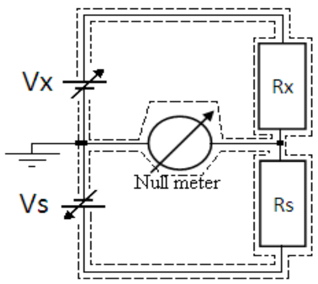

Figure 1 - Simplified schematic diagram of the modified Wheatstone bridgewith voltage sources Vx and Vs, null-detector, reference resistor Rs and unknown resistor Rx. Dashed lines indicate the shielding of cables and resistors.

3. MEASUREMENT HARDWARE

The system hardware consists of two Fluke 5720A calibrators, a set of standard reference resistors, a thermohygrometer, connection and interface cables, and a computer to control the system.

The unknown resistor and the reference resistor can be placed in air or oil bath, to stabilize the measurement temperature. Interconnection cables should have adequate insulation, such as those made of Teflon ™. This type of cable, however, has parasitic capacitances, which in combination with the high values of measured resistances leads to high-time constants, in the order of hundreds of seconds. This problem can be solved by using an active guard system [4].

4. MEASUREMENT METHOD

Calibration is performed by balancing the bridge, and calculating the unknown resistance by means of the ratio between the voltages of each calibrator and the reference resistor value.

The bridge equilibrium is also realized by reversing the direction of the current in the resistors, and the value of the unknown resistor Rx is the average between the measurements realized in both directions, in order to avoid offsets in the null detector and thermal emfs in the circuit . In addition, the bridge equilibrium is performed at the effective null of the detector, a condition obtained by making the calibrator voltages equal to zero volt and with all connections made.

The value measured in this condition by the null detector is considered as the real null. This determination is performed before and after each voltage adjustment.

5. MEASUREMENT SOFTWARE

The user interface allows greater flexibility to the measurement system and improves control of the instrumentation. The software was developed using the LabVIEW™ platform from National Instruments, available in the lab.

This platform was combined with a calibration database to correct the voltages generated by the calibrators used, increasing the flexibility of the system. The developed system makes all the control of the equipment in an automated way, including the generation of the voltages, the polarities exchange, the reading of the null meter and the reading of the thermohygrometer.

The calibration of the resistor with the application of several different test voltages can also perform. The system automatically generates files with the configuration information and data from the readings performed.

5.1. Balancing algorithm

The balancing algorithm works in a way that minimizes the offsets effects of the bridge and the detector used. First, the value of the detector is measured by making the voltage of the sources equal to zero volt, and the value measured by the detector is considered as the true null of the system.

After that, the nominal ratio values between the standard resistor and the unknown resistor are generated, and the detector value is measured again. Zero volt are generated next in the sources and the null is measured, in order to verify if it does not drifted during the measurement sequence, as shown in [1].

From these values, the voltage is adjusted in order to obtain the null, and this sequence is repeated in both current directions. The resistor value is obtained from the average between the ratios with direct and reverse polarity. Figure 2 below shows a simplified scheme of the balancing algorithm:

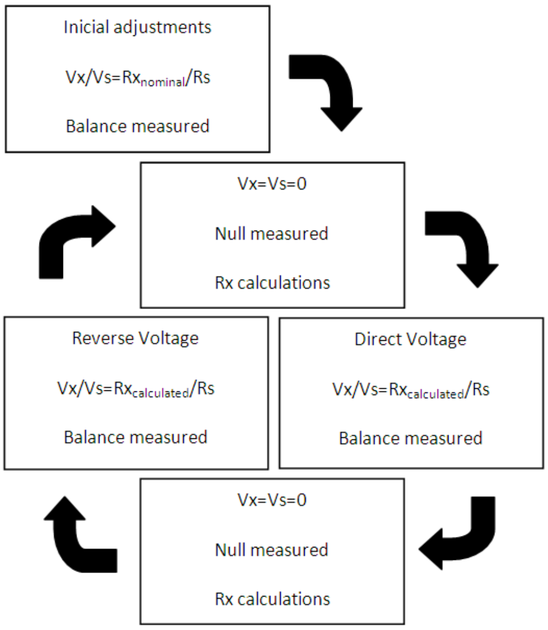

Figure 2 - Simplified diagram of the balancing algorithm.

6. MEASUREMENT RESULTS

Initial tests demonstrated a high degree of agreement between the values measured using the developed system and the values measured using the present measurement system. The tests consists in four series for each nominal resistance value, each one representing the average of a minimum of 10 measurements. Figures 3, 4 and 5 present the results obtained for each series for the three resistors:

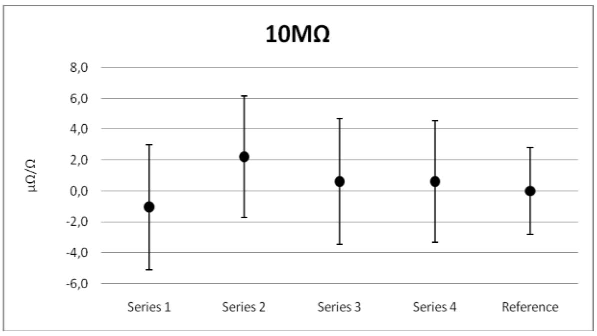

Figure 3 - Measured values for the 10 MΩ resistor.

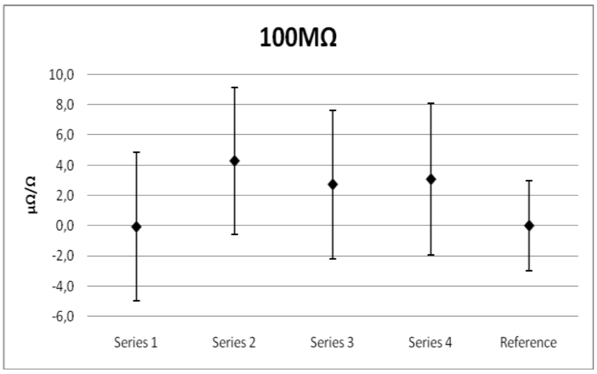

Figure 4 - Measured values for the 100 MΩ resistor.

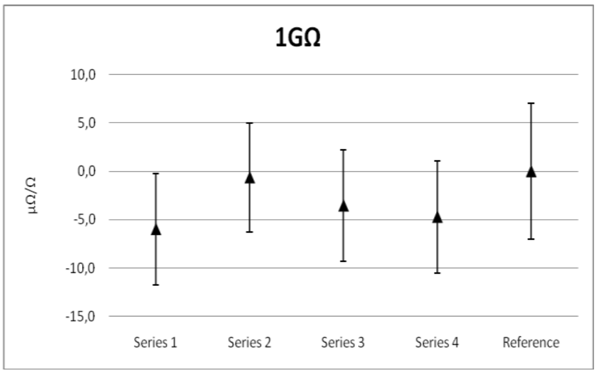

Figure 5 - Measured values for the 1 GΩ resistor.

The results obtained from the measurement were compared to the results presented at resistors' calibration reports. Then, the normalized error was calculated. This comparison is shown in table 1.

Table 1. Normalized error between measurements (en)

Nominal Value	Series 1	Series 2	Series 3	Series 4
10 MΩ	0,21	0,46	0,12	0,13
100 MΩ	0,01	0,75	0,47	0,53
1 GΩ	0,66	0,07	0,39	0,52

As can be seen in the figures and table shown, the results obtained are in good agreement with the calibration values of the resistors. The uncertainty, using the developed system and the step-up methodology, decreased for the 1 GΩ resistor, considering the calibration with the present system used. The research continuity involves the calibration of resistance values up to 100 TΩ. The participation in international comparison to values above 1 GΩ will enable the subsequent increase in the scope of services offered by Inmetro.

7. REFERENCES

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