SOFTWARE APPLICATION FOR SEMI-AUTOMATIC MEASUREMENT OF HIGH VALUE STANDARD RESISTORS

Luís Ribeiro [(1)], Mário Nunes [(2)]

Laboratório de Medidas Eléctricas, INETI, Lisbon, Portugal
Phone (351) 217165141 Fax (351) 217143997
[(1)] e-mail: luis.ribeiro@ineti.pt [(2)] e-mail: mario.nunes@ineti.pt

Abstract - *This paper describes the development, under a graphical programming environment, of a software application to control a modified Wheatstone bridge for measurement and calibration of high value standard resistors. Intuitive panels allow an easy user interface to control the bridge (three high performance measurement equipment and a variable DC voltage source), through a GPIB bus and on screen indications to all non-automatic operations. The user can graphically preview the intermediate results and decide to accept or refuse the data. The data can then be used to calculate the temperature and humidity coefficients, and determine the final result along with the correspondent expanded uncertainty from a set of values for each calibration point. A database can be maintained for each resistor standard with this data.*

Keywords - Metrology, standard, resistor, bridge, software.

1. INTRODUCTION

The calibration of standard resistors is carried out at INETI by three different methods:

- through the use of a classical high-precision current comparator bridge, capable of performing measurements in the range $10^{-5}\,\Omega$ to $10^{7}\,\Omega$ with a standard uncertainty in the range of 1,2 μΩ /Ω to 10 μΩ /Ω;
- through the use of a teraohmmeter for the range of $10^{8}\,\Omega$ to $10^{14}\,\Omega$ with a standard uncertainty in the range of 1 mΩ /Ω to 10 mΩ /Ω;
- and for the same range, by the newly implemented method of a modified Wheatstone bridge[1] [2] [3].

To perform measurements with the third method, only a computer-controlled operation can achieve similar uncertainties, due to:

- The high number of DC voltage and current measurements to be performed in a minimum lapse of time;
- The need to validate each measurement within very restricted limits;
- Several reconfigurations of the circuit for one measurement;
- Several numeric real time calculations;
- Registration of the intermediate results;
- The need to physically isolate the bridge from the operator, due to the high impedances involved;
- The need to apply the test voltages in a smooth step-up increment;
- Numeric calculations to determine the final result and uncertainty.
- Maintenance of a database for each of the observed resistors for evaluations on long-term stability and temperature and humidity coefficient determination.

2. EXPERIMENTAL SETUP

As described in [3], this measurement method evaluates the ratio of two high value standard resistors based on the well-known ratio of two dc voltages.

Two sequential stages of operations are carried out:

- On the first one the voltage of the programmable voltage source is set to a value that corresponds to a exact nominal ratio to the value of the fixed voltage;
- On the second stage the ratio of the two resistors under evaluation is calculated.

At this point of implementation, there is the need to manually rearrange the cable configuration between the two stages and manipulate two low noise switches.

In the first stage, the value of the initial voltage to apply to the bridge is determined by automatically varying the dc voltage calibrator output and comparing it to an electronic reference standard through a Kelvin Varley voltage divider, set to the desired nominal ratio. A nanovoltmeter is used as a null detector and a low noise switch operated to invert its inputs.

The circuit is then reconnected as showed in the simplified scheme (fig. 1), to performed the second stage of operations, in which three devices are controlled:

- a dc voltage calibrator serving as the programmable voltage source (*E var*), in one branch of the Wheatstone bridge, in the range from 10 V to 1000 V;
- an electrometer (*D1*) to measure the balance current of the bridge, with measurement values in the order of a few hundreds of pA;
- a multimeter to measure standard platinum resistors to determine the temperature of the air bath and ambient.

A second low noise switch is used in this second stage to short-circuit the electrometer for the zero determination and to apply and/or invert the applied voltages to the bridge.

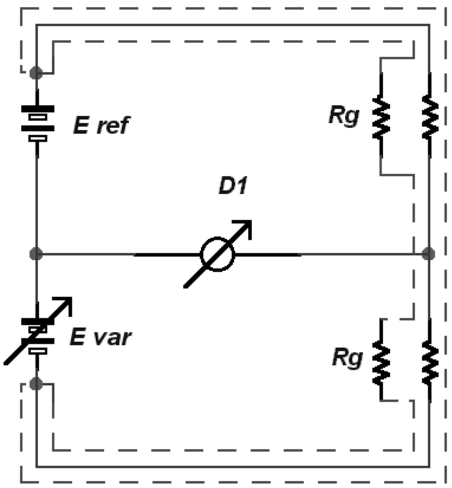

Fig. 1 - Simplified scheme of the modified Wheatstone bridge

3. SOFTWARE DEVELOPMENT

The platform selected to control the experimental set up, is a personal computer with a plugged-in GPIB interface board as all devices are equipped with that communication bus.

The graphical programming environment LabView[4], was selected due to its easiness to elaborate intuitive front panels where process sequence and intermediate data can be visualised in a graphical format.

Several independent software modules were developed and integrated in one package, allowing flexibility and control of the entire process (Fig. 2).

During the development of those modules, all the methods involved in computed determinations, were validated by parallel calculations in a preformatted Excel spreadsheet.

All parameters can be configured and saved in a separate file, namely: addresses of the GPIB devices, initial measurement set up of the four equipments under control, validation rules, time intervals and number of measurement cycles, nominal ratio of the resistors and channel definitions for temperature measurement.

At the end of the process, the data can be saved or discarded by the operator.

3.1. Module for the determination of one value

To obtain a *single value* from the measurement device in use, the system always performs a validation of the data in terms of stability of that measurement, in which several cycles of repeated readings are performed.

One *data point* is obtained through a series of 20 sequential readings. The standard deviation calculated and compared with the predefined value for validation. If the standard deviation is greater than the validation rule, that series of readings is repeated.

The determination of a *single value* is then obtained from the mean of several measured *data points.* A maximum number of repeated complete cycles is defined to prevent never-ending loops caused by any malfunction or bad connections.

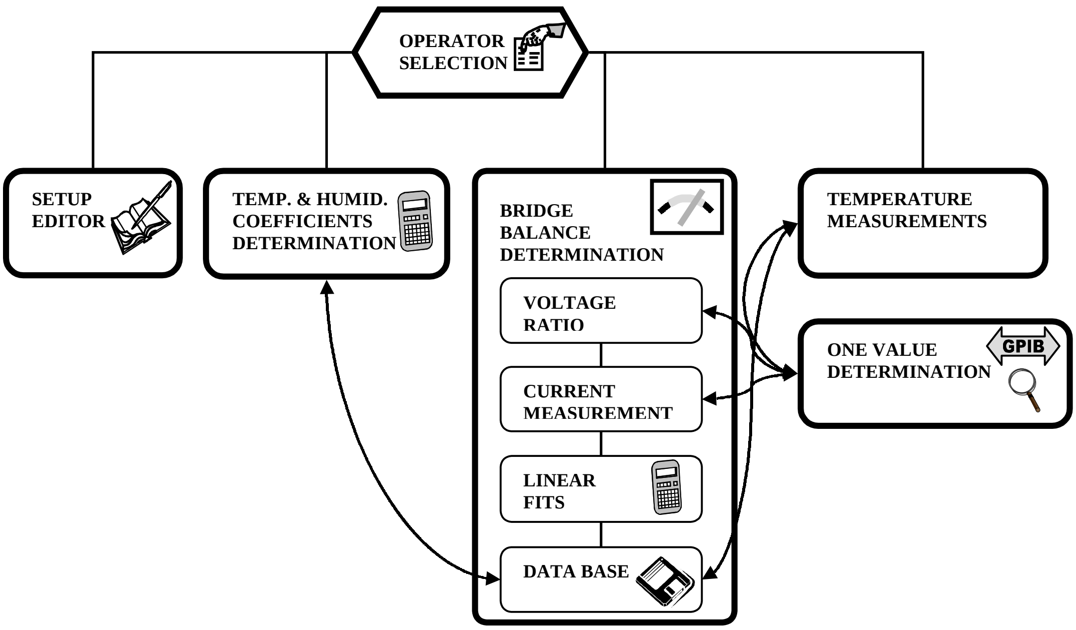

Fig. 2 - Block diagram of the developed modules

3.2. *Module for the determination of a zero balanced nominal voltage ratio*

This module is designed to control a programmable variable voltage source and read a nanovoltmeter to set the initial value of the voltage (V_0) applied to one branch of the Wheatstone bridge, corresponding to a predefined nominal ratio.

The variable output voltage is fed to a Kelvin Varley voltage divider, set to the nominal ratio of the resistors under study and its output compared with the fixed voltage output. The voltage difference is then measured by the nanovoltmeter.

The variable voltage source is controlled by the programme and changed until the voltage difference read by the nanovoltmeter reaches a predefined minimum value. A finer null adjustment can be obtained manually if the user decides to go further.

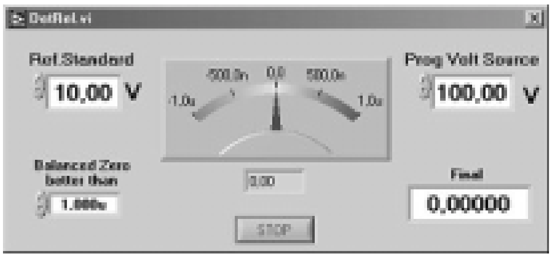

Fig. 3 - Front panel of the zero balanced module

3.3. *Module for the measurement of the ambient and air bath temperature*

Pt 100 resistors connected to a multimeter and a built-in scanner are used to measure the temperature. Two of them are located inside the air bath, close to the resistors under evaluation. Another two are used to measure the room temperature.

In a sequential order, all specified channels are read and the readings validated. A standard first order coefficients conversion is applied to get the temperature values displayed on the screen output and afterwards registered for future evaluations.

At this stage of development, a stand-alone device provides the value of ambient relative humidity.

3.4. *Module for the current measurements*

To determine the null point of the Wheatstone bridge, two sets of three individual current measurements and three circuit zero determinations are carried out:

1) The first determination of the circuit zero is measured with the inputs of the electrometer short-circuited with the resistors to be measured. The user, to establish the connection, must operate a manual low noise switch, after an indication provided by a popup window with a drawing showing the exact position for the switch;
2) After a similar indication to establish the bridge circuit, test voltage is applied in a smooth step-up increment, by controlling the programmable voltage source, to avoid current surges in distributed capacitance of the circuit, as voltages can go up to 1000 V;
   The first current measurement ΔI_1 is made to determine the first point of non-balance. This point represents an approximate value of the difference of the nominal resistors ratio to the voltage ratio.
3) An adjustment to the programmable voltage source, by applying a new calculated value ($V=V_0+\Delta V$ were $\Delta V=\Delta I_1 * R$), is made to null that difference. A second measurement is then made, giving a near to zero value;
4) A third current measurement is made by applying a 20% increase on the voltage correction ΔV to ascertain the consistency of the data with a linear fit;
5) A second determination of the circuit zero is measured;

An alert window then asks the user to reverse the polarity of the applied voltage sources, pressing a manual switch after which steps 2 to 5 are repeated.

A front panel was prepared to show a graphical representation of the current measurements, during the entire process (Fig. 4).

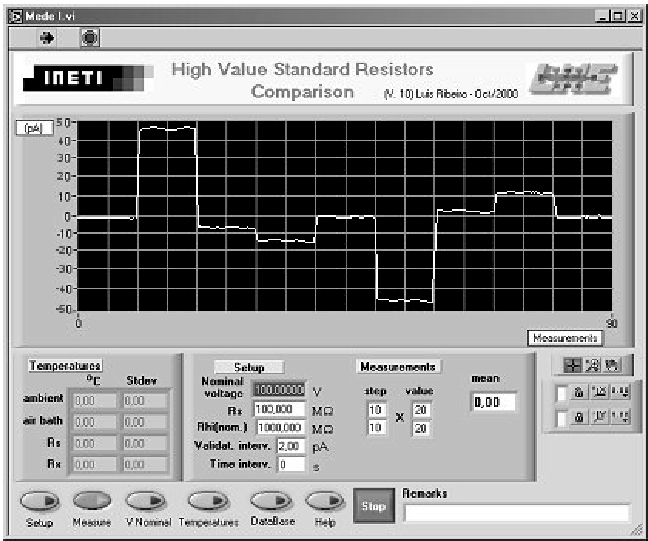

Fig. 4 - Screen shot of the current measurements module

3.5. *Module for the linear fits calculations*

Zero compensation is applied to each set of three measurements by subtracting the mean of the two consecutive zero readings.

Assuming a linear behaviour in the voltage range used, a linear fit, by the least square method, is applied to each set of three corrected current measurements to find the line and it's coefficients slope and intercept. The mean of the intercept values is then considered to best describe the ratio of the resistors under evaluation.

The mean square errors obtained from the fittings of each set of measurements will be used in the final uncertainty calculations.

After calculations, a graphical representation is displayed (Fig. 5) and the operator is then asked to save or discard the data.

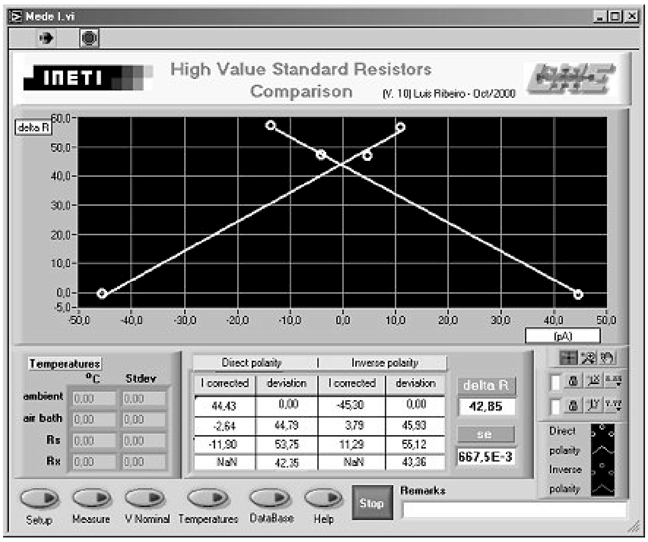

Fig. 5 - Screen shot of the linear fit calculations module

3.6. *Module for the database*

With the saved values, a database is created from which temperature and humidity coefficients can be calculated for each resistor. Corrections to the measured values can then be applied using those coefficients.

Long-term stability can be graphically represented with the new calculated data.

With this database, with values calculated from the 1 Ω laboratory primary reference value, the whole scale can easily be computed.

4. CONCLUSIONS

With the implemented setup and the developed software, we have the tools to manage not only the laboratory set of reference standard resistors but also customers resistors.

The expanded uncertainty was improved by a factor of at least 200 over the previously method, using a teraohmmeter, could only provide an uncertainty of 400 ppm.

Future developments foreseen for the measurement method can easily be implemented due to modularity of the software package, namely the control of an automatic low noise switch to replace the present manual one and the control of an air bath enclosure.

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