

1 Ω –10 k Ω high accuracy standard setup for calibration of multifunction electrical instruments

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Abstract. A temperature controlled 1 Ω and 10 k Ω standard resistors setup has been developed at National Institute of Metrological Research, (INRIM), to transfer the traceability to high accuracy multifunction electrical instruments used in Secondary calibration laboratories. These two standards are formed respectively by ten in parallel connected 10 Ω and 100 k Ω resistors inserted into a temperature controlled aluminium box. In addition, the 10 Ω resistors are put in separate place from the 100 k Ω resistors and in oil bath. Preliminary results of short time stability (2h) were about few parts of 10^{-8} .

1 Introduction

Some electrical instruments like digital multimeters (DMMs) and multifunction calibrators (MFCs), widely used as standards for precision measurements, are calibrated by means of a particular process, called “artifact calibration”, which requires only a small number of reference standards: 1 Ω and 10 k Ω resistance standards and a 10 V dc voltage standard [1÷3]. The possibility to transport from the primary laboratory (NMI) to the secondary laboratories only a voltage reference and standard resistors instead of delicate instruments like calibrators increases the accuracy of the traceability transfer and makes the calibration easier and technically convenient. To this purpose at National Institute of Metrological Research, (INRIM) a temperature controlled 1 Ω and 10 k Ω standard resistors setup has been developed to transfer the traceability to high accuracy multifunction instruments typically used in Secondary calibration laboratories. Moreover after satisfactory characterization results, the project of this setup could be also involved as Primary 1 Ω and 10 k Ω reference standard also used by National Metrological Laboratories and Institutes allowing to avoid the use of thermal enclosures often involved in high accuracy primary resistance standards as in [4] or specially made as in [5, 6]. A first attempt to directly realize a thermo-regulated reference standard resistor was already experimented at INRIM [7]. The actual realization is an improvement and an upgrading of that attempt involving the two main resistance standards useful to transfer the traceability to high accuracy multifunction electrical instruments.

2 Standard resistors

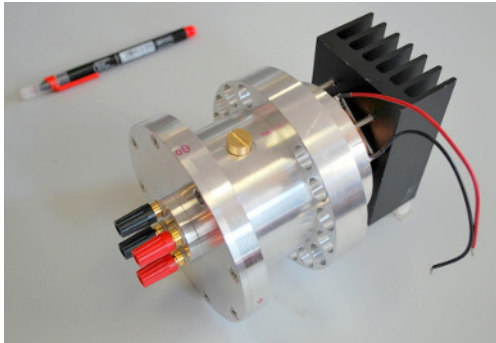
This system involves two nets of resistors. All the resistors are Vishay VHA type [8], selected for their specifications related the value tolerance, the temperature coefficient (TCR) and the short and long term stability. The resistors are hermetically enclosed in an oil filled aluminium cylinder. The tolerance of this type of resistors is ± 0.005 , with which there is a good possibility to obtain a value close to the nominal one as a result of the parallel connection. Their temperature coefficient less than $1 \times 10^{-6}/^{\circ}\text{C}$ and the long time stability, evaluated by the manufacturer on the order of $5 \times 10^{-6}/\text{year}$ are also satisfactory. To obtain a 1 Ω standard 10 matched 10 Ω VHA 512 resistors were connected in parallel with their leads and with manganin strap. The manganin was used instead copper due to its low temperature coefficient. The obtained value in parallel configuration shows also a low power coefficient, suitable to be measured with current up to 100 mA. The second standard, with 10 k Ω nominal value is obtained with a net of 10×100 k Ω matched and parallel electrically connected resistors. The resistors are always VHA512 type. The parallel connection is made with a strap of manganin as for the first net.

3 Development of the thermostatic box

The two resistors nets were placed into a structure obtained by turning an aluminum block. The structure is shown in Figure 1.

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Figure 1. Aluminium box. The photo shows the block connected with a TEC and a radiator. The ten resistors forming the 10 kΩ resistor are inserted into a hole series around the structure. The resistors forming the 1 Ω resistor are placed inside the box.



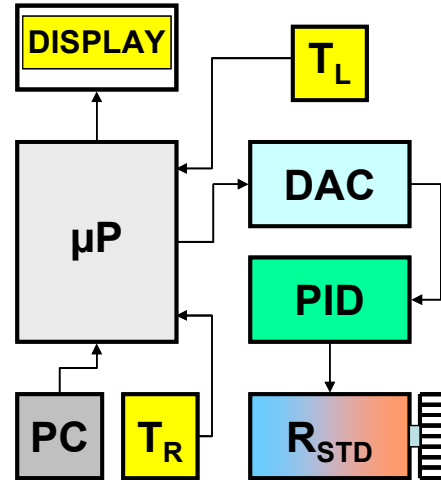
The net forming the 1 Ω standard is placed inside the box, in a cylindrical space obtained into the structure. This space is filled with mineral oil to maximize the temperature exchange between resistors and the case. The net of resistors is connected to four binding connectors placed on the cover of the box and fixed with thermal conductive resin. This solution was chosen to maintain the uniformity the temperature among the resistor connectors. The resistors of the second net forming the 10 kΩ standard, were placed into ten holes in an external ring of the structure. The connections of this standard are not critical related the thermal EMF, so they are not under temperature control. The bottom of the structure is mechanically connected to a Peltier element (TEC) connected in turn to a radiator. The structure is placed in a metallic box filled with polystyrene foam, while the radiator is placed outside the box. The TEC is supplied by a PID controller kept in a second box with the microcontroller and the power supply. The temperature controller is described in the next paragraph.

4 Temperature controlling system

The structure housing the resistors is temperature controlled by the system whose diagram is shown in Figure 2. The temperature control is based on a commercially available controller. The controller is a general purpose low noise PID with the possibility to use a NTC as temperature sensor. This circuit drives up to 3A directly to the TEC with an H bridge integrated. The temperature set point is defined by a dc voltage provided by a 16 bit DAC controlled by a circuit with a microcontroller. Due to the microcontroller the system can work both as stand alone or with a computer connection. In stand alone mode (see Figure 3) the microcontroller checks continuously both the temperature of the box and of the environment, the status of the battery and controls the display. The program to control the parameters of the standards was developed in Visual Basic, while the firmware of the microcontroller was written in C. Figure 4 shows the main frame of the

program with it's possible to read and set the temperature of the resistors case

Figure 2. – Block scheme of the temperature controlling system.



The display shows all the temperatures and the last resistors calibration value. Connected to a computer with the USB link it's possible to change the temperature set point, load the temperature of the box and the laboratory and to save the resistors calibration data into the microcontroller memory.

Figure 3.– Temperature controller system (on the left) and 1 Ω and 10 kΩ standards box.

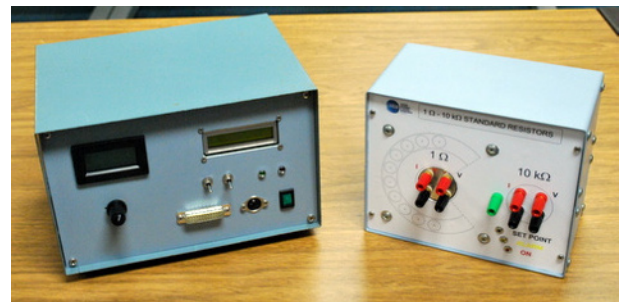
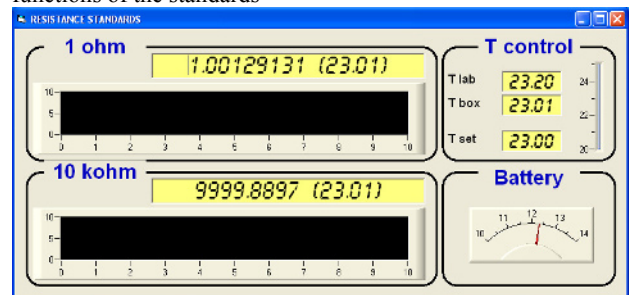
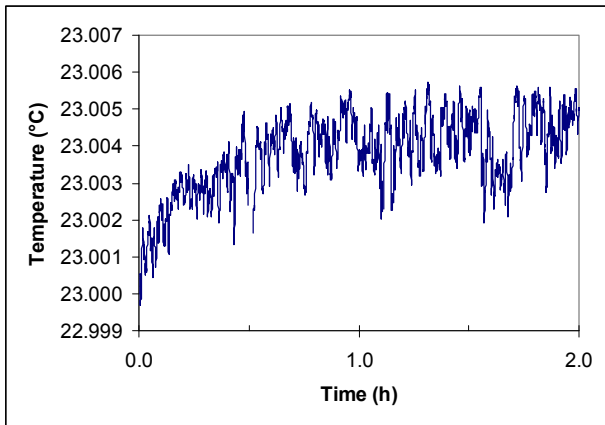


Figure 4. Main frame of the developed program to control the functions of the standards



The plot shown in Figure 5 shows the stability of the case with a the temperature set point at 23 °C evaluated in about 2 hours. Completed the transient due to the change of the temperature set point, the stability is better than 0.005 °C. The system requires about 30 min to change the temperature in a range of about 3 degree around 23 °C reaching the declared stability.

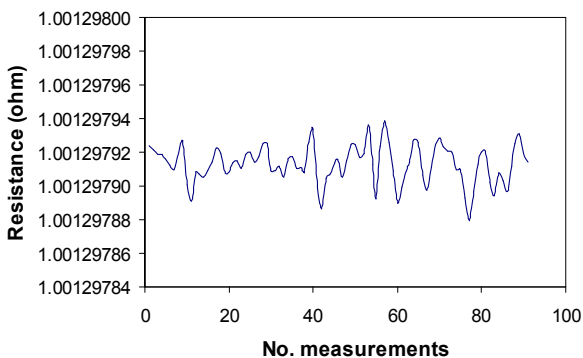
Figure 5. Temperature stability of the resistors case. The drift of the first part of the plot is a transient due to a change of the set-point.



5 1 Ω standard

A typical measurement on the 1 Ω standard is reported in the plot in Figure 6. The graph clearly shows both, the effect of the temperature control on the resistors and the thermal stabilization between the potentiometric connections of the standard. The short term stability of the standard obtained is similar to a 1 Ω standard normally used by the NMIs and kept into an oil bath. With all the used equipments, the measurements noise is less than 4×10^{-8} . Changing the temperature set point of the box the temperature coefficient of that standard has been evaluated in the range between 22 °C and 24 °C. The measured TCR is about $3 \times 10^{-6}/^{\circ}\text{C}$ confirming the data shown in the graph of Figure 6.

Figure 6– Series of measurements performed on the 1 Ω standard resistor against a standard resistor kept in a high stability oil bath in 1:1 ratio using a current comparator bridge.



6 10 kΩ standard

The net forming the 10 kΩ standard, kept in the block but out of the oil bath, shows a worse stability than the 1 Ω standard.

Figure 7. Evaluation of the TCR of the 1 Ω resistor. The measurement has been made opportunely setting the set point of the temperature controller.

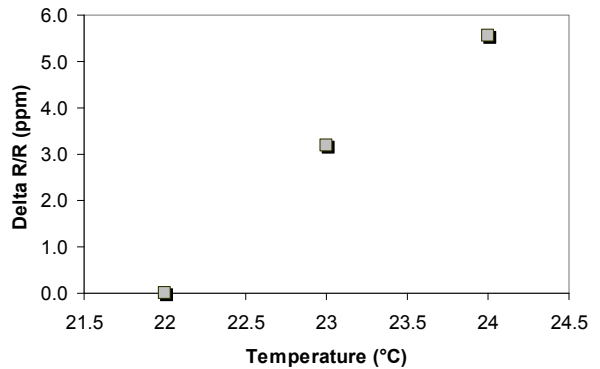
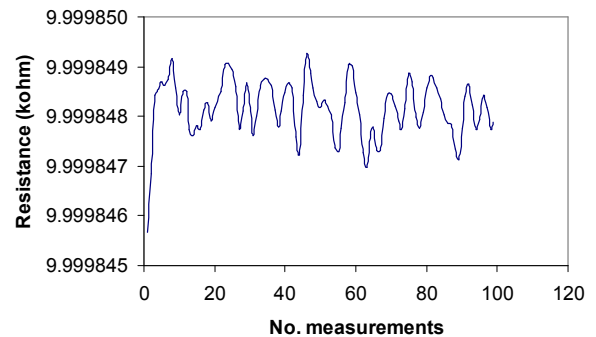


Figure 8. Measurements made on the 10 kΩ standard with set point at 23 °C



The TCR is about $8 \times 10^{-6}/^{\circ}\text{C}$, but considering the effect of the temperature controller the effective stability increases more than two orders.

7 Conclusions

These first characterization tests on the 1 Ω-10 kΩ high accuracy setup as well as its high thermal stability showed encouraging results so that this setup can be further investigated to evaluate its attitude to act as 1 Ω-10 kΩ primary reference standard both for maintaining the resistance unit in top level Laboratories and Institutes, both as travelling standard to calibrate multifunction electrical instruments by means of the “artifact calibration or employed for high level inter-laboratories comparisons. In the future could be further improved the stability of the thermal control system with the aim to reduce variation at a level of 0.001 °C.

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