Fabrication of High Value Standard Resistors for ICE-LMVE

Isabel Castro[1], Dean Jarrett[2], Marlin Kraft[2]

[1]Laboratorio Metrológico de Variables Eléctricas – Instituto Costarricense de Electricidad, San Pedro de Montes de Oca, San José, Costa Rica. Tel: +506-2001-2374, email: bcastro@ice.go.cr

[2]National Institute of Standards and Technology, 100 Bureau Drive, Stop 8171, Gaithersburg, MD, 20899, USA. Tel: +301-975-4240, Fax: +301-926-3972, email: dean.jarrett@nist.gov. Tel: +301-975-4239, Fax: +301-926-3972, email: marlin.kraft@nist.gov

***Abstract* — In Costa Rica, the Laboratorio Metrológico de Variables Eléctricas (LMVE) at the Instituto Costarricense de Electricidad (ICE) develops and improves measurement capabilities to promote and support the industrial innovation and development in the country. It's a pertinent remark that the resistance standards as well as the dc voltage standards are used to determine other electrical quantities such as electrical power, energy, electrical current or capacitance. A set of nineteen high value standard resistors from 100 MΩ to 100 GΩ were fabricated and measured at the National Institute of Standards and Technology (NIST). A subset of these standard resistors will be used as resistance standards for ICE-LMVE.**

***Index Terms* — Measurement, resistance standards, measurement techniques, precision, stabilization time, uncertainty.**

I. Introduction

A joint project on high resistance standards was conducted at the National Institute of Standards and Technology (NIST) with a guest researcher from the Instituto Costarricense de Electricidad (ICE) during 2015. The project was in support of the NIST strategic alliances with the institutions participating in the Inter-American System of Metrology (SIM) and NIST commitment to strengthening the measurement infrastructure in the Americas. The ICE guest researcher collaborated in the construction of high resistance standards in the range of 100 MΩ to 100 GΩ as well as scaling and measurement techniques using the dual source bridge method [1]. The results of this collaboration will improve the traceability chain for high resistance measurements used by ICE. Knowledge of other measurement techniques, such as the use of guarded Hamon transfer standards, direct current comparator bridges, and teraohmmeters were also part of the training program at NIST [2].

II. High Value Resistance Standards for Measurement and Calibration

The high resistance standards (up to 100 GΩ) available in the ICE-LMVE to perform their measurement and calibration work are commercial air-type resistance standards. These resistors are used as primary, working, or transportable transfer standards for the calibration of resistance ranges of multi-function calibrators and multimeters.

ICE-LMVE standards had been calibrated by other National Metrology Institutes (NMI) since 2010. The 100 GΩ resistor had been presenting a particular problem with its long stabilization time, as noted by the calibration provider NMI. Figure 1 shows that at least 1000 s is needed between the moment when the voltage is applied and the moment when the first stable measurement is taken.

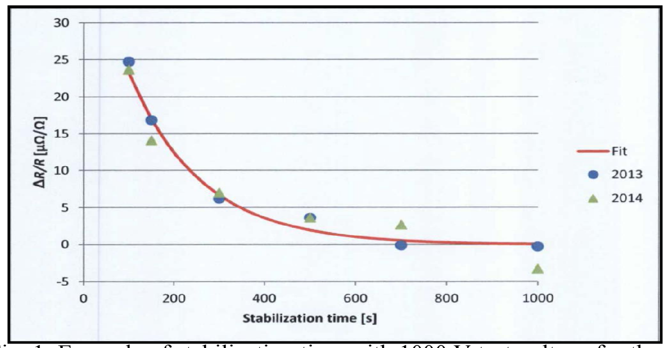

Fig. 1. Example of stabilization time with 1000 V test voltage for the 100 GΩ primary standard resistor used at ICE.

Measurement at ICE of this resistor showed that it has a drift rate of - 50 μΩ/Ω/year, with a temperature coefficient on the order of 250 (μΩ/Ω)/°C and a 1 (μΩ/Ω)/V voltage coefficient. An anticipated outcome of the training program at NIST was to construct a 100 GΩ standard resistor with improved stabilization time, drift, temperature and voltage coefficients for ICE to use as a primary standard in their calibration laboratory.

III. High Value Resistance Fabrication

The main objective in the fabrication of resistances standards was to construct at least one set of high resistance standards (100 MΩ, 1 GΩ, 10 GΩ and 100 GΩ) with good temperature and voltage coefficients, lower stabilization time and low drift with the possibility of a lower difference from the nominal value. The additional set of resistance standards would improve the robustness of the traceability chain and the quality control of high resistance measurements at ICE.

Precious metal-oxide film type resistance elements [3] have good characteristics for tolerance, stability, and temperature coefficient at resistance levels of 1 MΩ and above. Also, the resistors feature low noise and a high linearity because of a low voltage coefficient and low temperature coefficient, which makes them a good choice for high resistance standards.

The 100 MΩ and 1 GΩ resistance elements were heat treated and then hermetically sealed into cylindrical brass tubes, using glass-to-metal seals soldered to each end of the brass tubes. Near each end of the brass tubes there are also soldered copper tubes used to purge and fill the resistor container with an inert gas to provide a clean and moisture-free environment for the resistor element. Hermetically sealing the resistor element eliminates the seasonal humidity effects of resistance decrease due to surface leakage across the element and stress-induced change due to swelling in insulators in contact with the resistance film. [3]

The 10 GΩ and 100 GΩ resistor elements were hermetically sealed using the same procedures used for the 100 MΩ and 1 GΩ resistor elements except that the solid brass tube was replace with a metal-insulator-metal tube. Polytetrafluoroethylene (PTFE) and borosilicate glass were the insulating materials used. This metal-insulator-metal design allows the metal ends of the tube to be driven at guard potential, suppressing leakage currents flowing across the glass insulator of the seals. [3]

Each hermetically sealed resistance element was packaged in an aluminum enclosure with coaxial connectors as shown in Figure 2. Each terminal of the resistor element was soldered to the inner terminal of an N-type female connector (Glass dielectric type, 50 Ohm Impedance). The outer terminal of each N type connector was soldered to the hermetically sealed container. The N-type connector is mounted on a rectangular PTFE plate on the top panel of an aluminum box, which isolates the N-type connectors from the aluminum box. Each hermetically sealed container uses a support made of visco-elastic material to provide vibration and electrical isolation of the hermetically sealed container from the aluminum box.

Fig. 2. Final Resistor assembly. 100 MΩ, 1 GΩ, 10 GΩ, and 100 GΩ resistors shown.

VI. Conclusion

A number of measurements were made on the final resistor assemblies in order to check the stabilization time and other characteristics of the resistance standards. Figure 3 shows the stabilization time for one of the 100 GΩ standard resistors fabricated during this project. From 120 s to 300 s, the resistor decreased by approximately 12 μΩ/Ω, but had no discernable change from 300 s to 700 s, indicating that the resistor has a 300 s stabilization time. This is a factor of three reduction from the 1000 s settling time of the 100 GΩ resistor used at ICE. [4]

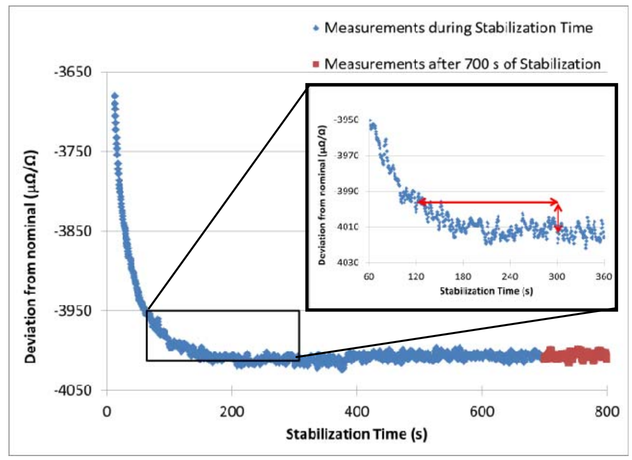

Fig. 3. Example of stabilization time, for a 100 GΩ resistor. Stability achieved after test voltage applied for 300 s.

Due to the natural aging process, the resistance standards long-term drift needs to be monitored in years to come. The expected yearly drift rate for the 100 GΩ resistors is about 10 μΩ/Ω, based on the control charts for similar resistors constructed with resistor elements from the same lot and following the same construction techniques at NIST.

Acknowledgement

I would like to thank NIST and SIM for this six months appointment as a Guest Researcher, and their extraordinary support in this process. I would like to express my gratitude to Dean Jarrett and Marlin Kraft for their expert advice and encouragement throughout this project.

References

[1] L.C.A. Henderson, "A new technique for the automated measure-ment of high valued resistors," J. Phys. Electron. Sci. Instrum., vol. 20, pp. 492 – 495, 1987.

[2] R. Elmquist, D. Jarrett, G. Jones, M. Kraft, S. Shields and R. Dziuba. "NIST Measurement Service for DC Standard Resistors", NIST Technical Note 1458, December 2003.

[3] R. Dziuba, D. Jarrett, L. Scott and A. Secula, "Fabrication of high-value standard resistors", IEEE, vol. 48, no. 2, pp. 333-337, April 1999.

[4] D. Jarrett and R. Elmquist, "Settling times of high-value standard resistors", CPEM 2004 Digest, p. 522, London, England, Jun, 2004.