Fabrication of High-Value Standard Resistors

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Abstract

The National Institute of Standards and Technology (NIST) has fabricated stable, transportable 10 MΩ and 1 GΩ standard resistors for use in an international comparison of high resistances. This fabrication process is being applied to the construction of standard resistors of values up to 100 TΩ, with initial results indicating significant improvements in stability and fewer adverse effects induced by mechanical shock and vibration.

Introduction

The highest quality standard resistors are usually of the wirewound type constructed with wire made from special high-resistivity alloys [1]. The highest value commercially-available wirewound resistor is a 100 MΩ unit. It is impractical to construct wirewound resistors of higher values because of the limiting maximum resistivity and minimum wire diameter available with these special wire alloys. For example, the length of wire needed to construct a 100 MΩ unit is approximately 18.7 km. Consequently, single standard resistors above a 100 MΩ are constructed using film-type resistance elements. Materials in film form have higher resistivities than the wire alloys because of the additional resistivity due to scattering of the conduction electrons at the boundary of the film [2].

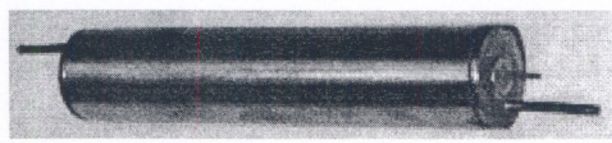
Generally, film-type resistors are not as stable as wirewound resistors, and the film types exhibit higher temperature coefficients of resistance (TCRs). If the film resistance elements are not hermetically sealed, moisture can produce two reversible effects: resistance decrease due to surface leakage across the element, and resistance increase caused by the swelling of the protective insulator resulting in pressure being exerted on the resistance element. Also, mechanical shock and vibration can cause resistance shifts and instabilities in film-type resistors. NIST has developed a fabrication process to alleviate or control some of these problems with high-value standard resistors.

Using this process, NIST has constructed several 10 MΩ and 1 GΩ standard resistors for use in an international comparison of high resistances. NIST is the pilot laboratory, and repeated measurements of these standards after travelling to various countries indicate that these standards have improved stabilities and are less susceptible to changes of resistance induced by mechanical shock and vibration.

Fabrication Process

The resistance elements of the 1 GΩ standards consist of precious-metal-oxide (PMO) film resistors that are commercially available. To improve their stabilities, these PMO film resistors are pre-aged by external heating [3]. This is accomplished by heat treating the resistors in an air oven at about 125 °C for over 100 hours. Either a single resistor or a series/parallel network of four resistors are mounted in a brass cylinder (15 cm x 3 cm OD) with a wall thickness of 6.35 mm. The resistance element is mounted in the brass cylinder using glass-to-metal seals which are soldered on brass end plates as shown in the photograph of Fig. 1.

Fig. 1. Hermetically-sealed resistor can assembly.



To reduce the number of dissimilar metal junctions, which will aid in diminishing thermoelectric effects, the resistance element leads pass through center tubes of the glass-to-metal seals prior to sealing in place with solder. Also soldered on the brass end plates are soft copper tubes that are used to purge the resistor can with dry nitrogen gas. After mounting the resistance element and before purging, the assembly is heated in an air oven at about 100 °C for approximately 4 hours to completely dry out the internal components of the can. Immediately upon removal from the oven, the resistor can is purged with dry nitrogen gas, allowed to cool to room temperature, and then hermetically sealed by crimping and soldering the ends of the soft copper tubes. The resistor can assembly is mounted in an aluminum enclosure to provide for increased electrostatic shielding as shown in the photograph of Fig. 2. The assembly is shock mounted in the

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enclosure using two isolation pads made of a highly damped visco-elastic material. The resistor terminations are coaxial connectors mounted on grooved polytetrafluoroethylene (PTFE) circular plates on the top panel of the enclosure. The grooves in the PTFE plates extend the surface leakage path between the aluminum enclosure and the coaxial connectors. The resistor can is electrically isolated from the enclosure and electrically connected to the shield of one of the coaxial connectors. This provides for the resistor can to be operated either in a floating mode, a grounded mode, or to be driven at a guard potential. A calibrated thermistor, terminated to a two-conductor shielded connector on the top panel, is mounted on the resistor can to monitor its temperature.

Fig. 2. Completed 1 GΩ standard resistor.

The resistance elements of the 10 MΩ standards consist of wirewound, hermetically-sealed resistors that are commercially available. In contrast to the PMO film resistors, there was no need to heat treat these wirewound resistors to improve upon their stabilities. The 10 MΩ resistance elements were shock mounted in aluminum enclosures in a similar fashion as described above for the 1 GΩ standards.

Measurements

Three each of the 10 MΩ and 1 GΩ standards are currently being used in an international comparison of high resistances. NIST is the pilot laboratory for this comparison, and repeated measurements have been made on these standards after traveling to various countries. These standards were measured at NIST using either a guarded Wheatstone bridge system [4] or a guarded active-arm bridge system [5]. A control standard at each of these resistance levels was measured along with the traveling standards. These control standards were constructed at the same time and using the same fabrication process as for the traveling standards.

Preliminary measurements indicate no significant behavior differences between the control standards and the traveling standards. During transport, the traveling standards were subjected to temperature excursions from 16 °C to 26 °C, while the control standards were in a laboratory environment of (23.0 ± 0.5) °C. Also, preliminary measurements indicate a mean drift for the 10 MΩ and 1 GΩ traveling standards of (6.0 ±3.9) ppm/year and (18.2 ± 2.0) ppm/year, respectively. The relative standard uncertainties for these measurements are estimated to be 1 ppm for 10 MΩ and 3 ppm for 1 GΩ. In contrast, commercially available resistors of this type specify drifts of 15 ppm/year and >100 ppm/year for the 10 MΩ and 1 GΩ resistors, respectively.

Future Plans

NIST plans to apply this fabrication process to the construction of standard resistors of values extending to 100 TΩ. A set of ten 10 GΩ resistors have been completed for the construction of a resistance transfer standard. Smaller diameter brass cylinders were used for this set of resistors for compactness, and to eliminate the need for brass end plates; the glass-to-metal seals form the end plates. The soft copper tubes are located along the perimeter of the brass cylinder and near each end.

Conclusion

NIST has developed a fabrication process for the construction of high-value standard resistors. Significant improvement in stability and the elimination of humidity and pressure effects is achieved by pre-aging and hermetically sealing the film-type resistors. The shock-mounting technique appears to have eliminated any effects due to transport for both the wirewound and film-type standards.

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