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SETTLING TIMES OF HIGH-VALUE STANDARD RESISTORS

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Abstract

An investigation of the response of high-value resistance standards and elements to applied potential has shown that the processes used to prepare and construct high-value resistance standards can affect the settling times of these standards. Improvements made to the processes used at NIST to fabricate high-value resistance standards will be discussed.

Introduction

Since the mid 1990s, NIST has made significant efforts to support and improve the calibration services for high-value standard resistors in the range of 10 MΩ to 100 TΩ. This has included the implementation and development of new measurement systems [1,2], and the design and fabrication of new resistance standards [3]. This body of work has led to a reduction of calibration uncertainties for high resistance measurements. During the process of evaluating uncertainties, resistance standards were characterized with increased resolution and accuracy that revealed in some standards and elements a short-term instability, or settling time, that could now be characterized for specific resistors.

It is known that time constants [4] are of concern in high resistance standards and should be considered along with other factors such as long-term stability or drift, voltage coefficients, and temperature coefficients when selecting elements for fabricating high resistance standards. In the past, the settling time has sometimes been difficult to characterize and differentiate from random noise at resistance levels of 100 MΩ and above. Automation, improved measurement techniques, and reduction of expanded uncertainties by an order of magnitude has made the characterization of these subtle time effects for high-value resistance standards a routine process.

Investigation of Wirewound Resistors

Generally wirewound resistors have been used as check standards at the 100 MΩ level because of their low voltage coefficient compared to film-type resistors [3]. Measurements at NIST were made at this resistance level using a guarded Wheatsone bridge [5] with an expanded relative uncertainty of 40×10^{-6} at 100 MΩ. The guarded Wheatsone bridge has been replaced with an automated active arm bridge [1] that can measure 100 MΩ standard resistors with an expanded relative uncertainty of 8×10^{-6}. The factor of five reduction of uncertainty has provided a better calibration service but also revealed that at the 100 MΩ level, several of the check standards are settling time dependent as shown by example in figure 1. Historical data on several of these standards show a relative variation on the order of 10×10^{-6} which may be due to variable settling times allotted by different operators, when manually balancing the Wheatstone bridge.

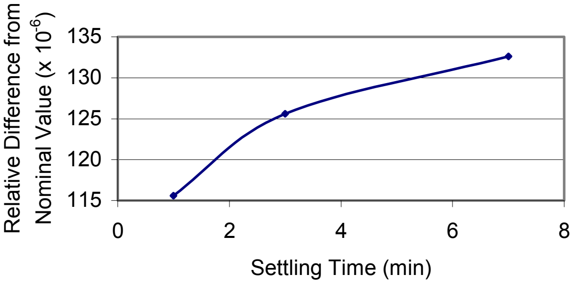

Fig. 1. Settling time of a 100 MΩ wirewound check standard.

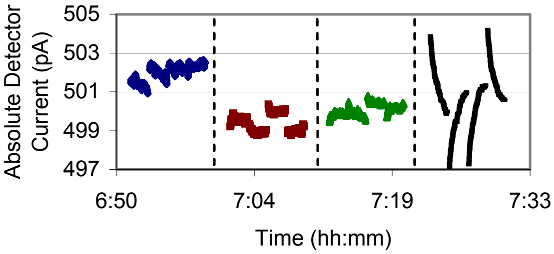

Fig. 2. Bridge current for four 100 MΩ standard resistors measured using substitution. Settling time is dependent upon resistor construction. First resistor is wirewound type Hamon transfer standard (10 x 10 MΩ), second resistor is wirewound type Hamon transfer standard (10 x 10 MΩ), third resistor is film-type (100 MΩ), and fourth resistor is wirewound type (100 MΩ).

Figure 2 shows data collected on four standard resistors of nominal value 100 MΩ. Each set of data shows the

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absolute value of the detector current for four bridge balances (+,-,+,-) per resistor. Each bridge balance was approximately 2 min including a 1 min soak interval during which current measurements were recorded but not included in the computations. The fourth set of data shows that particular resistor has an excessive settling time relative to the other three resistors shown in the plot. The construction of this resistor is based on a design that consists of many turns of wire of total length approximately 18.7 km. The mechanism is believed to be capacitive due to the close proximity of the many windings of 0.019 mm diameter wire. The first and second resistors shown in Figure 2 are Hamon transfer standards composed of ten sections of 10 MΩ standard resistors of the same design as the fourth resistor but using less wire per section. These two standards, and the third resistor, which is a film-type standard resistor, do not have long settling times like the 100 MΩ single unit standard resistor.

Film-Type Resistors

A similar analysis has been performed on film-type resistors at 100 GΩ, 1 TΩ, and 10 TΩ. Again the analysis showed that to a large extent, the magnitude of the settling time has to do with the construction of the resistance element and was not systematic.

The fabrication processes of film-type resistors vary in detail and application. The general principal is that resistance material, such as precious metal oxides (PMO), is deposited on a substrate to form the resistor. In some instances, this material is coated with a conformal coating, an epoxy, or sealed by some process to protect the material from humidity and contamination. The fabrication processes, many of which are proprietary to the manufacturer, have been found to influence the suitability of a resistance element to be used to fabricate standard resistors.

The fabrication process described in our earlier work relied on heat treatment and packaging to construct standard resistors from commercial resistance elements. Some resistor elements had been identified as suitable for the construction of 1 TΩ and 10 TΩ standard resistors due to their small temperature and voltage coefficients. At a later time, some additional elements were obtained from the same manufacturer. It was found that these later elements, which were hermetically sealed, did not perform as well as the original elements which had not been procured with hermetic sealing.

After a series of measurements, it was decided to try and remove the commercial hermetic seal and protective coating from the resistor element and see if this would improve the performance of the resistor. Figure 3 shows three sets of data for this resistor. The settling time was reduced by orders of magnitude by first removing the commercial hermetic seal and then nearly eliminated by additionally removing the conformal coating.

Summary

The settling times of wirewound and film-type standard resistors have been characterized. It has been shown that the time required for a standard resistor to reach a steady state after a potential is applied does depend upon the design of the resistor elements and the treatment of those elements during fabrication. We have demonstrated that by removing the dielectric materials and protective coatings applied during the fabrication process, the settling time of high-value resistors can be significantly reduced.

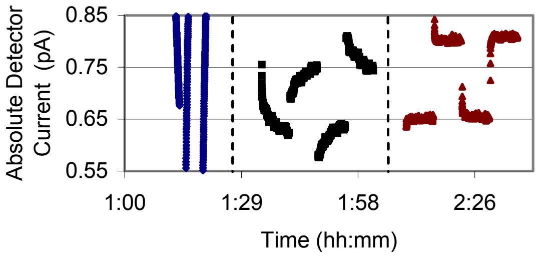

Fig. 3. Settling time of a 1 TΩ resistor. Shown are data collected for (1) unaltered resistor with commercial hermetic seal, (2) resistor after hermetic seal removed, and (3) resistor after both hermetic seal and conformal coating removed.

References

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