TERMINAL TIGHTNESS: IMPROVING THE STABILITY OF A FOUR-TERMINAL STANDARD RESISTOR

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Abstract

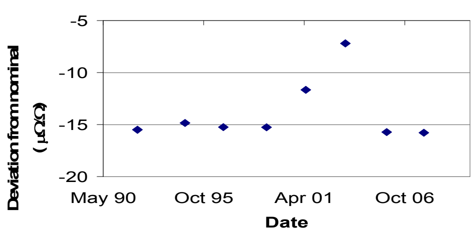
The four-terminal resistance of commonly used Tinsley Type 5685A 100 Ω resistors can vary significantly depending upon how firmly the terminals are tightened. Our measurements show a resistance to change of 12 nΩ/Ω for one resistor to an extreme case of 8000 nΩ/Ω for another resistor for which the body of one current terminal could rotate relatively easily. These findings makes it necessary to exercise care when connecting and reconnecting these resistors and also necessary to develop a way of effectively detecting or better still preventing terminal body rotation.

Introduction

The Tinsley Model 5685 standard resistors are widely used in both national measurement institutes and industrial laboratories (www.tinsley.co.uk). This resistor type has been used in several international comparisons of dc resistance, for example the 100 Ω comparison CCEM-K10 [1]. In this comparison two out of the three 100 Ω Type 5685A resistors behaved very predictably with residuals around a straight line fit to the pilot laboratory's measurements of 8.8 and 9.8 nΩ/Ω [1]. The third resistor however exhibited a sudden step change in value of around 150 nΩ/Ω and also a change in drift rate. This was attributed to a transport-induced shock effect.

We have observed a much larger instability in a customer's resistor of an identical type. This was found to be caused by a gradual loosening and rotation of the body of one of the current terminals resulting in a 8000 nΩ/Ω change in value (see Figure 1), presumably associated with the strain of the resistance wire. The customer subsequently modified the resistor to allow connection via permanently attached banana plug sockets. Since then the resistance value has remained close to the historical value.

Figure 1. History of calibration of a customer's Type 5685A 100 Ω resistor.



These two events led us to speculate whether the value of Tinsley Type 5685A standard resistors were in general dependent upon the amount of torque applied to the terminals when connecting the resistors and whether this dependence could responsible for part of the instability seen in the third CCEM-K10 Tinsley resistor.

This paper describes the results of resistance versus terminal torque measurements made on one of a group of Type 5685A resistors used in our laboratory.

Tinsley 100 Ω Resistor Construction

The Model 5685 resistors are of four-terminal construction and can be disassembled by unscrewing the thermometer well. For the 100 Ω resistor version the resistance wire is bifilar wound on a fiberglass cylinder with the individual turns loosely located using a series of fiberglass comb-like strips (Figure 2). The current and potential terminals are electrically connected to the end of the resistance wire using copper wires that are hard soldered to the ends of the resistance wire. The body of each terminal is insulated from the top plate of the resistor using white plastic spacers that are visible in Figure 2.

It is evident from Figure 2 that a rotation of any terminal body will strain the resistance wire and therefore change its resistance to some degree. There does not appear to be any keying mechanism for preventing such a rotation. Any creep of the plastic terminal insulating bushes will likely lead to loosening of these terminals, thus increasing the likelihood of a resistance change with applied torque.

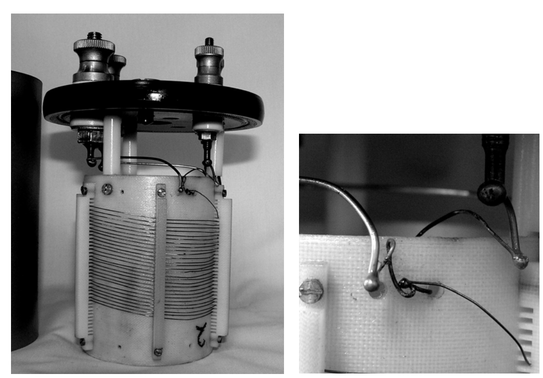


Figure 2. Internal construction of a Type 5685A 100 Ω resistor with a close-up of the joint between the resistance wire and the copper current and potential leads.

Measurements

A Tinsley Type 5685A 100 Ω resistor (labeled Ti664) was selected from the group of such resistors used at the Measurement Standards Laboratory. Ti664 was

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placed in a temperature-controlled oil bath and measured using a Measurements International Model 6010B resistance bridge. Several torques were used when attaching the current leads from the resistance bridge to Ti664's current terminals; light finger tightness (the default), 0.5 Nm, and 1.5 Nm. The 0.5 Nm value corresponds to a very firm finger tightening of the terminal. These torques were not sufficient to observably rotate the body of the current terminal. A series of other test conditions were also used where all the tests were carried out in the order shown in Table 1. Test F involved using pliers to apply roughly a 2 Nm loosening torque to the body of the current terminals and this led to an observable rotation of the body of approximately 2 degrees.

It is evident from these measurements that finger applied torques can cause resistance changes (12 and 14 nΩ/Ω) of the order of the residuals seen in the two "good" CCEM-K10 Tinsley resistors. Similarly a larger torque resulting in a small but significant rotation can produce a change (72 nΩ/Ω) of the order of the change for the "bad" CCEM-K10 Tinsley resistor. We have begun discussions with PTB regarding the significance of these results in relation to CCEM-K10 [2].

The comb-like support structure for the resistance wire seen in Figure 2 allows vibration of the 30 mm long wire sections and could result in a stick-slip type of motion of these sections. These factors would allow the possibility of transport or handling induced changes in resistance value. Test I was intended to determine whether slight mishandling of the resistor such as would occur during normal transit in a well cushioned box might cause a significant change in resistance. No significant change was observed during this simple test.

After Tests A to I were carried out the resistor was disassembled and the tightness of each terminal locknut checked. The locknuts on the bodies of both potential terminals were found to only be approximately finger tight. The effect of varying the torque applied to these terminals will be investigated in further measurements.

It is possible that this loosening of the potential terminals is due to stress-induced creep of the plastic insulating spacers on these terminals. If this is the case then all resistors of this construction will be prone to the terminal bodies becoming loose. It is important to develop ways of mitigating this problem in order to benefit from the intrinsic stability of the resistance wire used in this type of resistor.

Table 1 Change in value of Ti664.

Test Label	Action	Change relative to previous test's value (nΩ/Ω)
A	Initial value.	-
B	0.5 Nm tightening torque.	-12
C	1.5 Nm tightening torque.	-4
D	Removed from oil bath and replaced shortly afterwards- simulating a normal handling level of thermal and mechanical shock.	+1
E	Given a small mechanical shock.	+6
F	Approximately 2 Nm of torque applied in the loosening direction with a resultant 2 degree rotation of the terminal body.	-72
G	Again 0.5 Nm tightening.	+14
H	1.5 Nm tightening.	+6
I	Resistor inverted, shaken lightly and returned to the oil bath.	-1

Conclusions

The measurements reported here show that the torque used to connect the measurement leads to the standard resistor can have a significant effect on the resistance measured for a 100 Ω Tinsley Type 5685A resistor. The loosening of locknuts on the potential terminal for the resistor tested is a concern and can only be remedied by disassembling the resistor and tightening them. The effect on the resistance value of carrying out such maintenance will be reported at the conference, together with suggestions on how to mitigate this terminal tightness problem through either detecting or better still preventing terminal rotation. A simple interim approach would be to place a registration mark on the resistor body to allow any rotation to be detected.

Acknowledgements

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References

[1] B. Schumacher, "Final report on CCEM-K10: Key comparison of resistance standards at 100 Ω," *Metrologia*, vol. 44, Tech. Suppl., 01004, 2007.

[2] B.Schumacher, private communication.