A Transportable Thermoregulated Enclosure for Standard Resistors

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***Abstract* — This paper describes the development of a thermally regulated enclosure for standard resistor elements. The design, using a Peltier element, can work in a wide range of possible laboratory temperatures, with mK stability. Combined with a high quality resistance element, a robust working standard with 10^{-9} level relative stability is produced.**

***Index Terms* — Electrical resistance measurement, measurement standards, measurement techniques, resistors, temperature control.**

I. Introduction

Standard resistors for top-level metrological use are generally designed for use in a temperature controlled oil or air bath. Self-contained resistors mounted in their own thermoregulated enclosure also exist commercially, but are less common. The BIPM has used an in-house design based on a standard cell enclosure, modified to house resistors, for many years [1]. Other laboratories have also developed their own enclosures (eg [2]). In this paper we outline the development of a modernized enclosure designed to house resistors for use as working standards, both at the BIPM and during on-site QHR comparisons at other laboratories.

II. Design Aims and Specifications

Resistor elements with a first order temperature coefficient of better than 1 ppm/K are readily available. The form of the temperature variation around the room temperature region is parabolic, and this performance is obtained when the element is maintained at a minimum or maximum of the variation. The optimal working temperature depends on the resistor element, but is typically in the range 20 to 25 °C. If we wish for a stability in resistance at the level of 1 part in 10^9, we therefore need to maintain this internal temperature to a few mK. The external temperature is assumed to be a normal air conditioned laboratory, with a modest stability of ±1 K.

As the resistors are intended for use in NMI laboratories around the world (during a future series of on-site QHR comparisons organized by the BIPM), the nominal laboratory temperature could range from 20 to 25 °C. Allowing for a safety margin, the operational temperature range for the enclosure should be at least 18 to 26 °C. The internal temperature set-point (chosen using a precision bridge configuration) could therefore be a few degrees above or below the external ambient temperature.

The resistors will be used with a variety of CCC based bridges, which can be extremely sensitive to interference coupling (due to the sensitive nature of SQUID null detectors). The design must therefore feature complete isolation of the temperature control electronics from the measurement connections. The ideal approach is to use a fully screened definition of the standard compatible with use as an ac 'four terminal pair' standard (section 5.3 of [3]). This also has the advantage of controlling leakage resistances (which may become significant for standards of 10 kΩ and above).

The typical use envisaged for the resistors is as transfer standards for comparisons or as part of a calibration chain. For this purpose, the stability is critical in the 1 hour – 1 day time range. Longer term stability of the set-point is less important, as this can be considered as part of the inevitable drift of the standard's value. The rejection ratio for external temperature is also important, as the standard may be moved between rooms during measurements, and could be subjected to external temperature changes of order 1 K.

III. Details of Enclosure Design

The temperature control is implemented using a thermoelectric element (TEC), allowing for cooling as well as heating. In most configurations, the internal temperature will be above the external, so this is assisted by a heater element with a second control circuit.

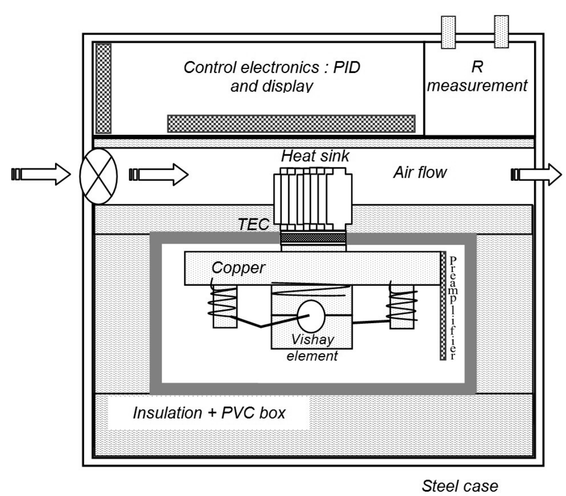

Fig. 1. Schematic of the enclosure design.

(A larger range of heating or cooling by the Peltier element alone could be achieved with a higher current output in the main control circuit, and this may be implemented in a future version).

Fig. 1 shows the general layout of the enclosure. The resistor element used here is a hermetically sealed bulk metal foil type from Vishay (VHA series [4]). It is mounted in good thermal contact with a copper block, which provides both thermal mass and electrical screening. Mechanical pressure and vibrations are limited by the use of a soft thermal pad between the resistor body and the copper clamp. Posts on the block are used for heat-sinking the connecting leads to minimize perturbations from the outside. The copper block is enclosed in an isolated box; the window for mounting the TEC provides the only thermal link through the insulation. A heatsink on the external side of the TEC is coupled to the outside via fan-assisted air flow.

The preamplifier of the temperature control circuit is mounted inside the isolated box. This improves the stability of the components used to control the set-point, and hence the overall thermal gain of the system. The control circuit is a purely analogue PID system; no digital clocks are present, minimizing the risk of creating electromagnetic interference. A display is provided, showing the temperature difference from the set point, with a gross or fine scale. This is useful to rapidly check that the standard is stable before commencing measurements. Measurements terminals are solid copper and are connected via a 2 x 2 twisted pair shielded cables. Wires are PTFE insulated and a small gauge size is used to minimize perturbation by the external temperature. Wires are connected to resistor pins using low FEM solder. These connections are ideal for 1 or 100 Ω standards; for higher values, or ac use, miniature coaxial cables can be used.

IV. Performance of Prototype Enclosure

The system has been tested using an environmental enclosure to provide external temperatures in the range 18 to 27 °C. Fig. 2 shows the response to an external step in temperature from 25 to 23 °C.

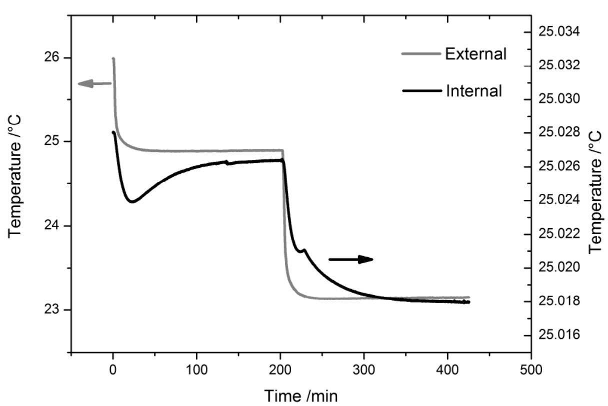

Fig. 2. Response of the enclosure to an external temperature step.

The internal temperature response shows a shift of around 8 mK for this disturbance, with a time constant of the order 1 hour. There is some scope to optimize the gain of the control electronics, and improve the rejection ratio for external perturbations. With a stable ambient temperature, the internal temperature shows fluctuations of less than 1 mK over periods of several days.

The Vishay resistance element used has a temperature coefficient of order 0.1 ppm/K, so the performance achieved is good enough for 1 part in 10^9 relative resistance stability in normal laboratory ambient conditions.

Future Development

The main aim of the development is to provide a set of robust, compact standards in values 1 Ω, 100 Ω and 10 kΩ that can be used as working standards during on site QHR comparisons. For this particular purpose, the resistor elements need to be characterized for any dc-1 Hz difference, as the BIPM transportable bridge operates at 1 Hz [5]. This is particularly critical for 1 Ω standards, which can have significant low frequency variations due to Peltier heating effects. The long term stability of the Vishay elements at the level of parts in 10^8 or 10^9 is so far not proven, but the use as working standards relies only on short term stability, so this is not a large risk. Data on the longer term stability can only be collected in use. The enclosure will also be put into service for secondary ac-dc resistors used in the BIPM quadrature bridge.

VI. Conclusion

A first version of a temperature controlled enclosure for resistor elements has been built. It shows sufficiently stable performance to obtain 10^{-9} relative stability in the final resistance standard. A series of standards based on this design will now be constructed for use in future BIPM on-site QHR comparisons. The design should also find other applications where compact, stable secondary standards of resistance are required.

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