LETTER TO THE EDITOR

Self-validating thermocouples based on high temperature fixed points

To cite this article: J V Pearce et al 2010 Metrologia 47 L1

View the article online for updates and enhancements.

Related content
- Miniature Co–C eutectic fixed-point cells for self-validating thermocouples
  O Ongrai, J V Pearce, G Machin et al.
- A miniature high-temperature fixed point for self-validation of type C thermocouples
  O Ongrai, J V Pearce, G Machin et al.
- Evaluation of the Pd–C eutectic fixed point and the Pt/Pd thermocouple
  J V Pearce, H Ogura, M Izuchi et al.

Recent citations
- A Self-Validation Method for High-Temperature Thermocouples Under Oxidizing Atmospheres
  S. Mokdad et al
- Performance of Pt–C, Cr $$\text{C}_3$$ –Cr $$\text{C}_2$$ –C, Cr $$\text{C}_3$$ –C, and Ru–C Fixed Points for Thermocouple Calibrations Above 1600 $$^\circ$$ C
  J. V. Pearce et al
- A miniature high-temperature fixed point for self-validation of type C thermocouples
  O Ongrai et al
LETTER TO THE EDITOR

Self-validating thermocouples based on high temperature fixed points

J V Pearce¹, O Ongrai¹,², G Machin¹ and S J Sweeney²

¹ National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK
² Advanced Technology Institute and Department of Physics, University of Surrey, Guildford, GU2 7XH, UK

Received 23 October 2009, in final form 21 December 2009
Published 7 January 2010
Online at stacks.iop.org/Met/47/L1

Abstract

We report the development of a self-validating high temperature thermocouple, whereby a high temperature fixed point of metal–carbon eutectic alloy forms an integral part of the thermocouple measuring junction, permitting in situ calibration.

When used at high temperatures (above 1100 °C) thermocouples are prone to substantial calibration drift. To gauge the extent of the drift, for example in an industrial setting, it is highly desirable for the thermocouple to be calibrated in situ. We report the development of a self-validating thermocouple, employing high temperature fixed points of metal–carbon eutectic alloys [1, 2] to form the measuring junction. A small cylindrical graphite crucible containing the fixed point material forms the measuring junction, after the fashion of Tischler and Koremblit [3] who used pure metal fixed points. The thermocouple wires are attached to either end of the crucible, so the crucible itself forms the electrical connection between the two thermoelements. The high electrical and thermal conductivity of the graphite ensures the good electrical and thermal response of the thermocouple. The melting and freezing plateaux of the eutectic alloy are observable in the thermocouple emf as the temperature of the measuring junction passes through the fixed point temperature.

The self-validating thermocouple described here is based on a conventional type R thermocouple. The miniature crucible comprises a hollow graphite cylinder with a lid. The length is 10 mm, outer diameter 6 mm, wall thickness 0.5 mm and internal volume 124 mm³. The thermoelements are attached to the crucible by threading them through 1 mm diameter holes at either end of the crucible. The crucible is filled with a metal–carbon eutectic alloy. The arrangement is shown in figure 1. We report here the first results with the Co–C eutectic and discuss alternatives under investigation.

All measurements were performed in a horizontal tube furnace (temperature uniformity within ±5 °C over 20 cm) in an argon atmosphere. The measuring junction was placed in the most uniform region of the furnace. The furnace temperature was then cycled above and below the melting temperature of the Co–C eutectic (1324 °C). Plateaux are shown in figure 2.

Although the measuring junction contains the fixed point ingot, it is also in thermal contact with the external environment. Adopting the notation of [3], during the melt or freeze the thermocouple emf will always represent a temperature between the fixed point temperature \( T_0 \) and the furnace temperature \( T_f \). The analysis in [3] considers the relationship between \( T_f \) and \( T_0 \), and the difference between the two, \( \Delta T = T_f - T_0 \). The thermocouple emf when the crucible is at the furnace temperature is \( V_s \), and the emf during the melt or freeze plateau is \( V_p \). During melting or freezing, \( V_p \) is offset from the ‘equilibrium’ \( V_p (\Delta T = 0) \) (i.e. the emf when \( T_f = T_0 \)). This emf offset is proportional to \( \Delta T \). To gain a measure of the relationship between \( V_s \) and \( V_p \), different furnace offsets \( \Delta T \) were employed to examine a large number of melts and freezes.

The influence of the furnace temperature on \( V_p \) for this thermocouple is shown in figure 3. The uncertainty in \( V_p \) is determined by adding in quadrature the repeatability of readings during the melt or freeze, the repeatability of 10 melts or freezes, and half the emf range during the melt or freeze (to estimate the uncertainty in locating the plateau).
Here, the equilibrium value of $V_p$ is $14,964 \, \mu V \pm 10 \, \mu V$, approximately 0.2 °C below the reference function value (at 1324 °C) of 14,967 µV. The slope of the best fit line in figure 3 is 4.3 µV/µV. Thus, during the melt or freeze, for every 4.3 °C of furnace offset from the fixed point temperature, the calibration overreads by 1 °C with the same sign as the furnace offset. This means that the emf overreads during melting and underreads during freezing. No freeze was visible for $-4^\circ C < \Delta T < 0^\circ C$, but a melt was observed on re-warming.

We are currently investigating this technique of self-validation with Pt/Pt–Rh thermocouples (including types R, S and B), Pt/Pd thermocouples and W–Re thermocouples (including types C and D). The thermocouples developed
so far make use of the metal–carbon eutectics Co–C and Pt–C. Nonetheless, in principle all metal–carbon eutectic alloys and metal (carbide)–carbon eutectic alloys can be used as the fixed point. Also under development is the incorporation of multiple fixed points in one crucible, so that self-calibration of a thermocouple can be performed at a number of temperatures, and the use of sheaths to protect the graphite crucible from oxidizing environments. It is envisaged that these developments could have widespread use in industry, either directly or as witness sensors determining the drift rate of other nearby sensors.

References