A Dual Heat Pipe Thermocouple Scanner

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Abstract
This paper describes the development of a thermocouple homogeneity scanner that can measure changes in the Seebeck coefficient over the length of a thermocouple (Fig. 1). The device was developed at the Measurement Standards Laboratory of New Zealand and the manufacture and commercial sale has been licensed to Isothermal Technology Ltd, UK (Isotech).

A thermocouple operates using the Seebeck effect, which is the redistribution of electrons in a conductor when exposed to a temperature gradient. Every material has a different Seebeck coefficient. By pairing two different materials (thermoelements) a thermocouple can be formed. No current flows in the thermoelements when they are placed in a temperature gradient. The measured emf is only due to the difference in electron charge redistribution between the two thermoelements.

Thermocouple inhomogeneity describes the variation in Seebeck coefficient along the length of a thermocouple, and is typically caused by variations in the chemical and metallurgical state of one or both thermoelements. The effects of inhomogeneities cannot usually be mitigated by calibration. Further, the act of exposing some types of thermocouples to temperatures as low as 100 °C during calibration may induce changes in the Seebeck coefficient that further complicate any analysis of the effects [1].

To identify variations in the Seebeck coefficient over the length of a thermocouple many in-house scanners have been developed by NMIs, most employ an existing furnace, oil- or salt-bath. However, many of these systems are slow, taking up to 1 h to complete a single scan, and have low resolving potential. Both problems are caused by poor thermal coupling between the scanning medium and the thermocouple under test.

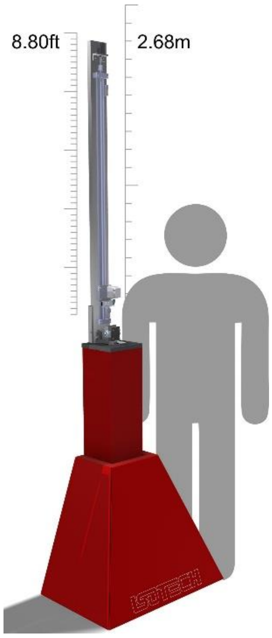

Figure 1. Dual heat-pipe scanner.

Ideally, the scanner should operate with two isothermal zones, with the narrowest practicable temperature gradient between them [2], as shown in Fig. 2. Hence, only the small part of thermocouple exposed to the gradient will generate an emf. Any widening of the gradient region will reduce the resolving potential of the scanner.

The system developed by MSL uses water vapour to transfer heat directly to the thermocouple, making use of the latent heat of vaporisation that occurs when there is a state change between liquid and vapour. However, with the ability to apply large quantities of heat very quickly, comes the associated problems of thermal conduction within the thermocouple. Hence, the rate of heat flow needs to be controlled through an active rather than passive scanning system. Traditional scanners use pauses in the scanning processes to allow thermal equilibration before measuring the emf.

However, in the current system such pauses combined with the large heat flow would result in a widening of the thermal gradient region, lessening the resolution. Consequently, an active and continuous scanning process must be used to compress the temperature gradient region, while at the same time making dynamic measurements of emf and thus allowing the Seebeck coefficient to be calculated.

The theory behind an ideal homogeneity scanner is not new and was described by Reed in the early 1990's during a concerted effort at that time to better understand the thermal drift processes that take place in all thermocouples [3]. However, Reed did not conceive of the phase change type scanner employing heat-pipe technology, instead he pursued high-heat capacity low-temperature gallium eutectics. The idea of a scanner based on a phase change medium was first implemented by White and Mason [4], also from MSL. This new scanning technique made possible many of Reed's suggestions for an ideal scanner, approximately twenty years after he first described it.

Heat-pipes operate by piping a working fluid around an enclosed space and often employ a liquid vapour transformation process to ensure thermal equilibrium. Heat-pipes can have thermal conductivities up to 400 times that of copper. The MSL-ISOTECH scanner uses not one but two separate heat-pipes (Fig. 2). The high-temperature heat-pipe uses water and is open to the atmosphere, operating at ~100 °C (steam-point). The second smaller heat-pipe uses acetone and is closed, operating at ~20 °C (ambient air temperature).

The thermocouple is passed from the acetone heat-pipe into the water heat-pipe. Thermocouples are directly exposed to the steam, thus ensuring a high level of heat transfer. The ability to pass the thermocouple between two highly uniform temperature zones makes high-accuracy high-resolution scanning possible. The 'low' temperature (~100 °C) of the hot-zone ensures the thermocouple under test is not likely to be altered (metallurgically or chemicaly) during the scanning process. Scanners operating above 200 °C willl change the Seebeck coefficient of most thermocouple types, often invalidating the homogeneity scan.

The Scanner

The current version of the MSL-ISOTECH Scanner is the result of five years of intensive research by Emile Webster, with the generous support of others in the MSL temperature team in helping to overcome some of the theory and engineering challenges which make this instrument unique.

In the new version the hardware, electronics and software have been optimised and integrated, were possible, to create an easy-to-use high-accuracy thermocouple scanner, suitable for measuring inhomogeneities in both base- and rare-metal thermocouples.

A Peltier control system has been added to the acetone heat-pipe, enabling a sharper scanning temperature gradient and better knowledge of the gradient magnitude.

Emile Webster visited Isotech in September 2018 to help manage the technology transfer.

Isotech have been developing the MSL pre-production device into a full production model incorporating some engineering changes whilst maintaining functionally critical components. The first commercial models are planned for the first quarter of 2020.

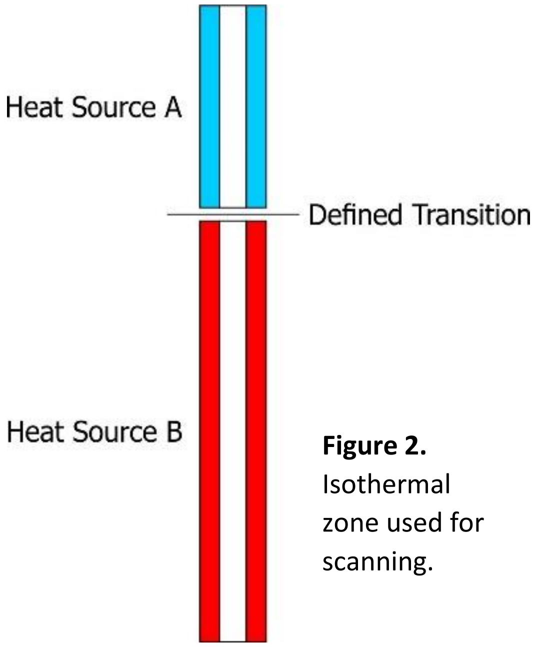

Figure 2. Isothermal zone used for scanning.

In use the test thermocouple is fixed to a linear slide and the thermocouple can be moved between the two heat sources with a scanning resolution of between 2 mm and 5 mm (diameter dependent). The process is fully automatic and takes less than 20 minutes.

Benefits

As well as the rapid and accurate scanning system, the user benefits from the unique software that takes the results and process the data into information that the user needs to assess the acceptability of the thermocouple being investigated. The software also makes it easy for the user to calculate an uncertainty component due to inhomogeneity when calibrating thermocouples.

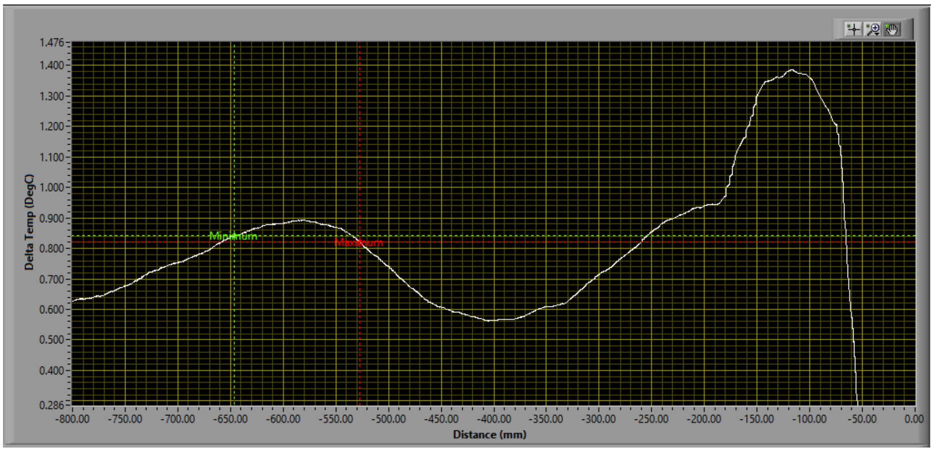

Figure 3. Scan of a Type K Thermocouple exposed over a 1 m length to a maximum temperature of 950 °C.

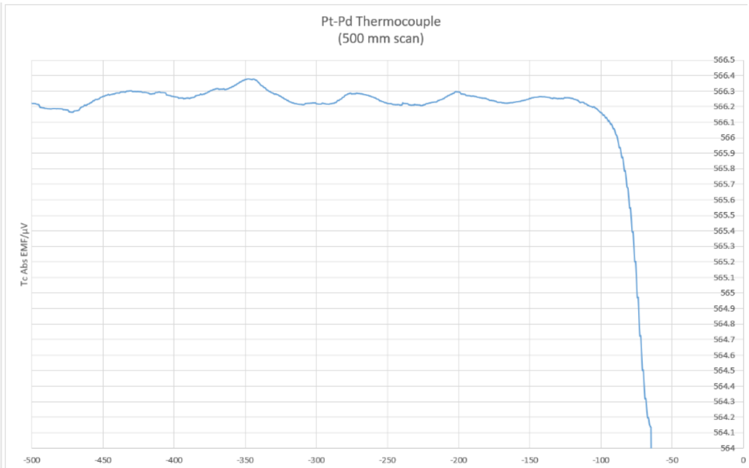

Figure 4. A scan over 500 mm of a Platinum-palladium thermocouple

Conclusion

Both manufacturers and users of thermocouples will benefit from the commercial availability of a scanner able to assess the inhomogeneity of thermocouples. Primary and secondary laboratories can now provide realistic calibrations based on accurate inhomogeneity information.

The scanner can be used to determine:

- The uncertainty due to inhomogeneity
- The location of damaged regions that should be avoided
- Whether an annealing procedure has been successful
- If wire/cable manufacturing processes meet quality standards or tolerances
- Whether a thermocouple is damaged or faulty and unfit for use or calibration

[1] **Webster E S** 2014 *Int. J. Thermophys.* **35** 574–595
[2] **Webster E S** and **White D R** 2015 *Metrologia* **52** 130–144
[3] **Reed R P** 1992 *Temperature, its Measurement and Control in Science and Industry* **6** 519–524
[4] **White D R** and **Mason R S** 2010 *Int. J. Thermophys.* **31** 1654-1662