Thermocouples – Compensating Circuits

This is the final article in a short series examining ways of looking after thermocouples (1–3).

A thermocouple converts a temperature difference into a voltage which is converted into a reading by a temperature indicator. The voltage is generated by the lengths of wire in the temperature gradient between the hot junction in the furnace and the cold junction at the indicator. In practice, the temperatures between the indicator and the furnace wall are low and the gradients are small. To reduce costs these lengths of thermocouple wire are replaced by base metal ‘compensating wire’, connected at the thermocouple ‘head’.

Compensating wires should generate the same voltage as the thermocouple wires they replace. (The indicating instrument corrects for the difference between its terminal temperature and the standard cold junction temperature of 0ºC.) Users can choose wire grades A or B (4) to replace thermocouple wire Types R (Pt versus 13RhPt) and S (Pt versus 10RhPt). Grade A has an error of ≤30 µV (equivalent to ≤2.6ºC at 1000ºC), with a maximum operating temperature of 100ºC. Grade B has a maximum permitted error of ±60 µV but has suitable insulation for use up to an operating temperature of 200ºC.

The compensating wires used for Types R or S are very similar: pure copper for the positive limb and 0.6%NiCu for the negative one. The international standard for insulation colour coding specifies orange for the outer insulation, orange for the positive and white for the negative. (The superseded U.K. standard (5) specified a green lead with white to code for the positive wire. Green is now used for Type K leads.)

Thermocouple Types R and S, made to either the International Practical Temperature Scale of 1968 (IPTS-68) or the International Temperature Scale of 1990 (ITS-90), can use the same compensating wire, as their voltage outputs differ by only 2 µV at 100ºC and 28 µV at 200ºC.

Type B (6RhPt versus 30RhPt) thermocouples require only connecting, rather than compensating, leads because the output is low at low temperatures. Using copper lead, with the thermocouple head at 80ºC, reduces the output by 17 µV, equivalent to an error of only –1.9ºC when measuring 1000ºC. However, the error will increase to –10ºC if the head is at 150ºC. The connecting wires should be colour coded grey and white (to lessen risk of connection to a mains voltage supply).

To check a Type R or S compensating circuit, link the limbs at the thermocouple head – the indicator should then show the head temperature; this can be independently verified. Alternatively, disconnect the lead from the head, twist the compensating wires together to form a ‘hot’ junction and place in boiling water, the indicator should show close to 100ºC.

Potential errors, when the head is at 80ºC, the indicator terminals at 30ºC and the hot junction at 1000ºC are:

(a) Type R used with copper cable under-reads by –330 µV (–25ºC).
(b) Type R used with compensating lead with the polarity reversed under-reads by –660 µV (–50ºC).
(c) Type R used with Type K cable reads high by +1734 µV (+130ºC).
(d) Type B used with Type R/S compensating lead reads high by +311 µV (+34ºC).

Minimising the head temperature by careful location, radiation shields or forced cooling, will keep the compensating wires within their operating range. Correctly used, compensating leads offer significant cost saving with only a small impact on measurement accuracy.

References
4. IEC 60584-3 Ed. 1.0 b., 1989-08-15
5. BS 1843:1952

The Author
Roger Wilkinson is a Principal Metallurgist at Johnson Matthey Noble Metals in Royston, U.K. He has worked with platinum thermocouples since 1987 in manufacturing, calibration and customer technical support.