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Thermocouples – Open Circuit Faults

This is the third in a series of short articles on looking after thermocouples (1, 2). The first article considered safeguarding performance while the second examined minimising drift. Compared with the erroneous readings seen when a thermocouple drifts, open circuit faults are immediately obvious.

An open circuit is usually caused by breakage of a thermocouple limb, but always check for poor connections to the compensating or connecting leads. Limb breakage generally occurs close to the hot junction where the wire is weakest and where the effects of contamination are greatest.

Contamination usually results in output drift, but may not if isolated in a short length of wire or in wire that is not in a significant temperature gradient. This parallels the 'wire bridge' method of calibrating a thermocouple, when a gold wire is used to form the junction between the two limbs and 'fails' at 1064.18°C. The gold wire does not affect the thermocouple output.

Contaminants act to reduce the melting point of the limb to below the maximum operating temperature, or to reduce the wire strength if a tensile load is present. The contaminant must alloy with Pt and be present in significant local concentrations, generally at the grain boundaries.

If protective sheathing and 99.7% purity alumina ceramics are used, and attention is paid to assembly cleanliness, contamination is usually only a problem where low melting point metal vapours (not oxides) are plentiful; more likely in a vacuum or reducing atmosphere. Contaminants that reduce the melting point of Pt to < 1000°C include P, As, Si, Sb, and Pb.

Metalclad or mineral-insulated thermocouple designs delay the effect of contamination on output, but ultimately cannot prevent failure if the concentration is sufficient to cause the cladding to fail. In applications where the atmosphere is partially oxidising, metalclads have been seen with a dark outer layer of 'immobilised' oxidised contamination.

However, tensile loading is the more general cause of limb breakage: just 28 g suspended for 100 h will break a 0.5 mm Pt wire at 1400°C (at 1200°C the load capacity is 45 g). Pt will form a 'bamboo' structure, that is, a chain of single grains each occupying the full diameter of the wire and often 1 mm long. Tensile breakage is then evident as single crystal slip, although higher loads will produce hot tears in either limb. To prevent tensile loading requires a systematic approach to eliminate both static and cyclical loading.

Static loading is caused when the thermocouple wires support all or part of the weight of the ceramic insulators. One-piece twin-bore insulators can be clamped at the head end but may fracture in service. Where an outer sheath is used the lower end of the twin bore should rest on the end cap, with the bead in a ground-out recess 5 to 10 mm back.

Cyclic loading is due to thermal expansions and contractions of the wires and insulators. The wires must be free to move within the insulator bores and must not be kinked. The bores should be well formed, giving sufficient clearance. The wires should extend from the insulator separator to give a 5 mm clearance gap to the bead.

However, even the best kept platinum thermocouples do not last forever. Within Johnson Matthey, bare wire thermocouples employed in stress rupture testing at 1400°C fail after many hundreds of hours of use, even though the thermocouples are mechanically well supported and being used in a clean oxidising environment. The eventual failure in these cases is due to evaporation of the wire through the formation of volatile Pt and Rh oxides.

R. WILKINSON

References

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