measurement matters

Making sense of thermocouples

Thermocouples are the most widely used temperature sensor. The simplicity of two wires connected to a meter has an obvious appeal. However, when high confidence in measured temperature is required, thermocouples can be a liability. Thermocouple literature often mistakenly states the junction is the source of the voltage. In fact, the voltage is generated along the length of the wire, and in a well designed thermocouple installation the junction does not contribute at all!

The thermocouple voltage arises because the electrons in metals are responsible for the conduction of both heat and electricity (hence thermo-electric effect). Wherever heat flows in a conductor, a voltage is generated. A good analogy is a water-filled pipe (see accompanying diagrams): the pressure in a water pipe is generated where the height of the pipe changes. In a similar manner, the voltage in a thermocouple wire changes only where the temperature changes. Also in the water pipe, so long as there are no bubbles trapped in the pipe, the total pressure depends only on the height of each end. In a thermocouple, with no defects in the wires, the total voltage depends only on the temperature at each end. Two different thermocouple wires generate different total voltages, and the difference between the voltages on the two wires allows us to measure temperature.

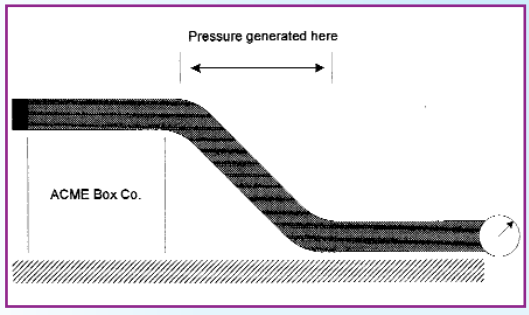

Figure 1: The water-pipe analogy of the thermocouple. The pressure in the pipe is generated only where there is a gradient. The total pressure depends on the end heights.

There are two basic rules for managing thermocouples:

1. Wherever thermocouple wire is exposed to temperature gradients, it must be free of mechanical, thermal, or chemical damage.

In Type K thermocouples, mechanical damage from a single bend may cause an error of a few degrees; wire used above 500 degrees Celsius and reused at lower temperatures is typically in error by three to eight degrees Celsius; and wire operating for long periods in a low-oxygen environment can be in error by as much as 30 percent (300 °C at 1000 °C). Similar effects occur in all thermocouple types, though rarely as bad as for Type K.

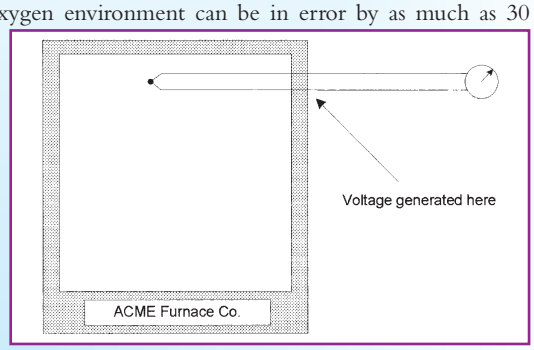

Figure 2: The voltage generated in a thermocouple is generated at the temperature gradients. In this example, most of the voltage is generated in the section of wire through the furnace wall. The total voltage depends on the end temperatures.

2. Where the wire is damaged it must be kept isothermal (at a uniform temperature).

Defects in the wire only have an effect if they are located in temperature gradients. This means wherever there is damaged wire including junctions, connections, joins, plugs, sockets, extension leads, etc, we must avoid placing them where there is heat flow, air drafts, or infrared radiation. Do not place thermocouple connecting blocks against furnace walls.

In particular, we must make sure that wire damaged during the manufacture of the junction is all at the same temperature so it cannot generate any voltage. The junction can be soldered, welded, peened, twisted, crimped etc. It does not matter because the junction does not generate the voltage.

To check a thermocouple installation, place the measurement junction in an ice bath (very close to zero degrees Celsius), and progressively wave a heat-gun over the full length of the thermocouple. If there are no problems, the thermocouple reading will not change significantly from zero degrees.

Article by Rod White,
Head of Temperature Standards,
Measurement Standards Laboratory of New Zealand.
Rod can be contacted at: r.white@irl.cri.nz