Mismatched thermocouple cables cause measurement error

Assume that a customer is using a type K thermocouple to take readings and that the instrumentation (transmitter or input circuit) is also designed for type K but that the customer for some reason has bought an extension cable for type N. Would there then be a measurement error, and, if so, how can it be compensated for? This is a common question asked of Pentronic and we will it discuss here.

A measuring circuit with a mixture of extension cables might look like the one shown in Figure 1. The section between the first splice (T_{splice} = 70 °C) and the reference junction (T_{ref} = 40 °C) consists of a type N cable whereas the thermocouple itself is type K, as is the instrumentation.

Table 1 shows the splices' temperature in degrees Celsius and also the corresponding emf (electro-motive force) in microvolts for the thermocouple type at issue here. The values are nominal and we must therefore hope that the real values lie within the relevant tolerance limits for the respective thermocouple types in accordance with the IEC 60584 standard. The relationship is given in equation (1), which specifies between the curly brackets which thermocouple type and thereby which table is intended.

$$E_{K\text{-}N\text{-}K} = \{E(T_{meas}) - E(T_{splice})\}_{TAB\ K} + \{E(T_{splice}) - E(T_{ref})\}_{TAB\ N} + \{E(T_{ref})\}_{TAB\ K} \quad (1)$$

Look at row 1 in Table 1. The measured temperature is 900 °C. The first splice between type K and type N maintains 70 °C and could be a terminal head that is heated by the protection tube's losses through a furnace wall.

Because the thermocouple voltage is non-linear to the temperature, the corresponding voltage level has been taken from the applicable table, where E represents emf in microvolts. The next point of interest is the return to the type K cable at the reference junction. Assume that the temperature in this case is 40 °C. The correct presentation would be $E_{K\text{-}K\text{-}K}$, where all the cable components are of the same type. $E_{K\text{-}N\text{-}K}$ shows the emf of the arrangement shown here. The difference, -56 °C, is the measurement error, which proves to be fairly constant across a large temperature range. The minus sign is because type N gives a lower output signal than type K. In its turn, the lower output signal, which is assumed to be a constant -56 degrees, assumes that the temperature difference along the extension cable (type N) is a constant 70 °C or 40 °C respectively, which is not likely.

There are three ways to compensate for the mismatching extension cable's differing sensitivity [μV/°C]:

1. The first and best way is to get the correct extension cable, in this case, type K.

2. The second way is, if possible, to ensure that the ends of the mismatching cable maintain the same temperature, ($T_1 = T_2$). All sensitivity is thereby zeroed out, which can be possible within a closer temperature range. See equation 2.

$$E(T) = S_{N+/N-}\,(T_1 - T_2) \quad (2)$$

where T is the temperature of the splices and S the extension cable's Seebeck coefficient.

3. The third possibility would be to compensate for the difference in voltage with some reverse voltage. However, it is not easy to make this arrangement responsive to temperature changes in, for example, a dynamic sequence of events such as a process start-up.

Which alternative is best must be discussed from case to case. The less work and cost involved in replacing the cable, the greater the reason for doing so. You must also consider your customers and what would happen if they discover that you are "fudging" with the cabling. Trust in a supplier's expertise strengthens a business relationship and makes it more likely that the customer will stay loyal.

If you have questions or comments, contact Hans Wenegård: hans.wenegard@pentronic.se

Thermocouple type K				Thermocouple type N			Indicator K	Presentation		Measuring error
T_{meas}	E_{meas}	T_{joint}	E_{joint}	E_{joint}	T_{ref}	E_{ref}	E_{ref}	$E_{K\text{-}K\text{-}K}$	$E_{K\text{-}N\text{-}K}$	ΔT °C
900	37326	70	2851	1902	40	1065	1612	38938	36924	-56
500	20644	70	2851	1902	40	1065	1612	22258	20242	-56
200	8138	70	2851	1902	40	1065	1612	9750	7736	-56

Table 1. $E_{K\text{-}K\text{-}K}$ is the nominal output signal with all type K cables. $E_{K\text{-}N\text{-}K}$ is that of the measuring circuit disrupted by the foreign thermocouple type. The difference ΔT appears to be constant across the measuring range 900 – 200 °C but this is actually not the case, because the protection tube's losses heat the the terminal head more at a high measuring temperature than at a low one.

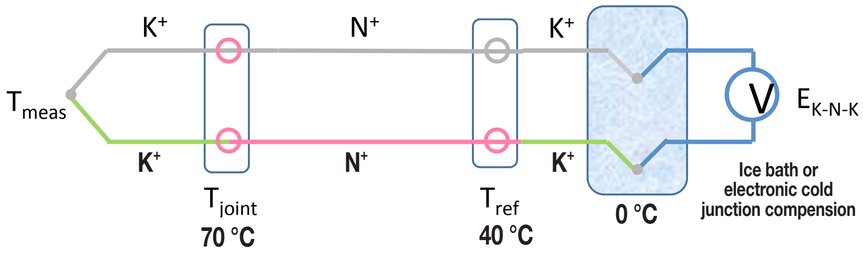

Figure 1. A thermocouple circuit is using a type K thermocouple to measure temperature. The splice between the terminal head and the reference junction has been done with a type N extension cable. A measurement error arises due to the differing Seebeck coefficients (sensitivities) of type K and type N.