FireRight

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TECH MEMO

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<u>Re:</u> Calibration Anomalies of the -200°C/+300°C Extended Temperature Range for Type T (Copper vs Constantan) Thermocouple Sensors

<u>Background:</u>

All FireRight temperature-measuring instruments share a potentiometric measuring circuit which is more or less identical, regardless of the type of thermocouple sensor used, or the temperature range of the instrument. This circuit includes a precision (low offset, low drift) dc input amplifier, and a five-segment "piecewise" analog linearizer.

The five-segment linearizer is needed to correct the nonlinear thermocouple temperature vs emf curve for the linear digital display system used on these instruments. The concept underlying the design of such circuits is rather simple ... the thermocouple's response curve over the temperature range of the instrument is arbitrarily divided into five segments with approximately equal maximum linearity errors. These segments are then separately re-scaled to provide mV/degree slopes which are approximately equal, and then reassembled as a single "linearized" response curve.

In reality, what results is not a perfectly straight line, but a straight line with five 'humps". Nonetheless, this approach can provide very respectable results. For example, the maximum linearity offset for the standard -125°F/+375°F temperature range is reduced from over 33°F to less than 2-degrees, with an average offset over the range of about 0.9°F (0.18%).

The tradeoffs associated with the design of analog linearizers of this type are not very subtle. Improved performance can be achieved by (1) using a shorter temperature range and/or (2) increasing the number of segments. Temperature ranges are usually a function of the application for the instruments, not a choice available to the circuit designer. The number of segments plugged into the formula, however, is limited only by practical considerations, which are:

> (1) The circuit is subject to the exponential “law of diminishing returns”. The degree of improvement diminishes with each additional segment. Perfection is impossible to achieve, and at some point the improvement achieved isn’t worth the circuit board real estate and component count required.
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> (2) Practical components (i.e., dual and quad op amps) suggest “practical” configurations of either three, five or eight segments. Three segment configurations are suitable only for special-purpose (short) temperature ranges, and eight segment configurations are almost always “overkill”. Happily, the five segment configuration (one quad op amp) nicely accommodates most practical temperature ranges, and is therefore the configuration usually found in practical controls.

History:

In April 1991, one of our customers requested that we change the -125°F/+375°F (-87°C/+191°C) standard range on one of our temperature limit controllers to -200°C/+300°C so as to better accommodate an application involving thermal shock test chambers.

In these applications, the temperature of the test specimen is forced to change very rapidly by moving the chamber temperature quickly and drastically well beyond the desired test specimen temperatures. As the temperature at some point on the test specimen stabilizes at the new high or low limit, the temperature of the chamber returns from its extreme excursion, and the two eventually meet at the new control point.

When the temperature sensor for the limit controller could not be located exactly at the same point as the controlling sensor, the indicated limit temperature would sometimes be taken beyond the -87°C and +191°C limits of its measuring range, causing the control to trip and sound its alarms.

The extended range was requested as a “fix” for an existing installation, and the design goal was to provide it on an “as needed” basis as a modification for standard units that would not involve any significant lead time or costs. These goals were met by recalculating component values for the existing circuitry.

Although almost doubling the length of the range would obviously degrade the output of the five-segment linearizer, its performance was still fairly respectable. Over most of the range (from +300°C to -100°C) the linearity error ranged from zero to a maximum of less than 3°C. In the lowest segment (-90°C to -200°C) the numbers predicted a maximum

error of just less than 9°C occurring at -150°C. In other words, the linearizer's performance was optimized by packing the largest part of the error into an operating area that would be seen only during periods of temperature transition and stabilization, while temperatures at or near actual control points would be quite accurately indicated.

Using Calibration "Fudge Factors" to Minimize the Maximum Linearity Error:

The actual calibration results realized with the extended range instruments has consistently reflected very close agreement between the design data and the real performance of the linearizer system, reflecting the predicted offset on the low end of the range.

Ordinarily, this has simply been accepted as rationalized above, the instrument being calibrated in the usual manner by "zeroing" it at -200°C and "spanning" it at +300°C.

However, the calibration can be significantly improved by offsetting the "zero" point to -206.3°C (emf = -5.700mV). As shown in the following tabulation calibration results, this reduces the referenced indication error by about half, without significantly affecting the indicating accuracy in other parts of the range.

Set °C	Temperature Indication: Orig Calib Temp	Orig Calib Error	"Fudged" Calib Temp	"Fudged" Calib Error
300	300	0	302	+2
280	279	-1	281	+1
260	259	-1	260	0
240	238	-2	240	0
220	218	-2	220	0
200	198	-2	200	0
180	179	-1	181	+1
160	160	0	162	+2
140	139	-1	141	+1
120	118	-2	120	0
100	99	-1	100	0
80	79	-1	81	+1
60	59	-1	62	+2
40	39	-1	41	+1
20	19	-1	20	0
0	0	0	2	+2
-20	-21	-1	-18	+2
-40	-42	-2	-40	0
-60	-62	-2	-60	0
-80	-81	-1	-79	+1
-100	-102	-2	-99	+1
-120	-126	-6	-122	-2
-140	-148	-8	-144	-4
-160	-167	-7	-164	-4
-180	-185	-5	-181	-1
-200	-200	0	-196	+4