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Achieving Ultra High Accuracy in Temperature Measurements With Thermocouples

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GEC Instruments has developed methodology, involving proprietary techniques in hardware and in software, to enable unprecedented accuracy in temperature measurements with thermocouples. Supporting data from several different instruments, manufactured and calibrated at GEC, are included in the following pages.

We have been able to achieve ultra high accuracy in measuring temperatures with thermocouples by using special proprietary techniques to minimize the reference junction error, the voltage measurement error and the linearization error. And we are able to minimize the effects of thermocouple wire error by means of a very easy-to-use two point calibration functionality within our PinPoint Monitor software. In addition to accuracy in temperature measurements, our techniques enable measurement resolutions of ±0.005 °C or better and channel to channel uniformities of ±0.01 °C.

The error in measuring temperature with thermocouples with any thermocouple instrument is related to several factors that combine together to affect the overall accuracy of the measurement:

Thermocouple wire error: this is the error resulting from the fact that a given sample of thermocouple wire will not exactly meet the temperature versus millivolt relationship given in the standard tables. The most accurate designation is for Type T thermocouples. The errors allowed for type T over the range -65 to 130 °C are 1.0 °C for standard wire and 0.5 °C for Special Limits of Error (SLE) wire.

Reference junction error: this is the error in determining the temperature of the reference junction, sometimes called the “cold junction”. The reference junction error in our instruments is typically less than 0.005°C, a value that is even smaller than is typically found in those systems that use an ice bath for the reference junction.

Voltage measurement error: this is the error in the measurement of the small voltage produced by the temperature difference between the measuring junction and the reference junction.

Linearization error: The temperature vs. millivolt relationship for thermocouples is inherently non-linear. The accuracy of the conversion from voltage to temperature depends on the method that is used to make this conversion. Most commonly there is a fit to standard polynomials or interpolation within the table values. Both of these methods are subject to some degree of error. We have developed our own polynomials to minimize linearization errors to less than 0.002 °C, while converting from voltage to temperature, when using the standard reference functions for type B, E, J, K, N, R, S or T thermocouples.

The following pages show the small errors following calibration of 7 different precision thermocouple instruments, manufactured and calibrated at GEC Instruments, with different numbers of channels and different sizes of thermocouples. These data include thermocouples supplied by GEC instruments, thermocouple probes supplied by other commercial sources, and thermocouples supplied by the customer.

Except for Instrument ELO1, page 8, the thermocouples calibrated with a given instrument were made from the same roll of SLE wire.

In each instance, a systems calibration of the instrument and thermocouples together was performed at two temperatures, one near the low end of the range of interest and one near the high end of the range.

The thermocouples were immersed, together with a standard reference thermometer, to a depth of 8" in a stirred water bath. Resolution of thermocouple readings was ±0.005 °C or better.

The standard reference thermometer was an NIST traceable precision thermistor thermometer with an accuracy of 0.003°C and repeatability of 0.0005°C. This thermometer was used to read the bath temperature, which was controlled to a stability of 0.001°C at each calibration temperature

Following the two point calibration, thermocouple readings were recorded, along with temperatures from the precision thermistor thermometer, at stable bath temperatures at approximately 5 °C intervals in the range of interest to provide a post calibration verification of thermocouple reading accuracy.

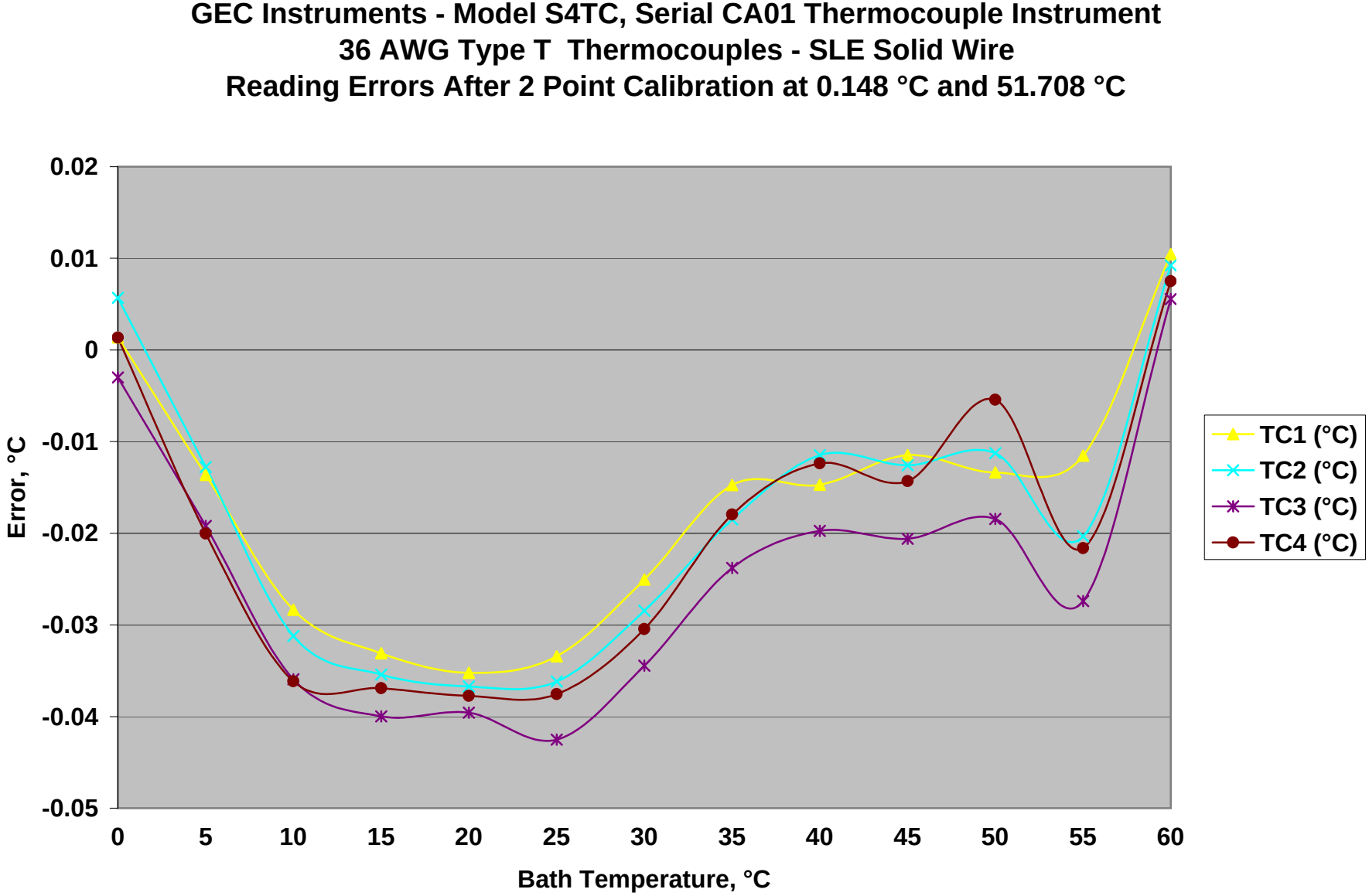
Data on the following pages are from those post calibration verifications. Errors in the plots were calculated as thermocouple reading - bath temperature reading.

Errors include a combination of voltage measurement error, reference junction error, linearization error, and thermocouple wire error.

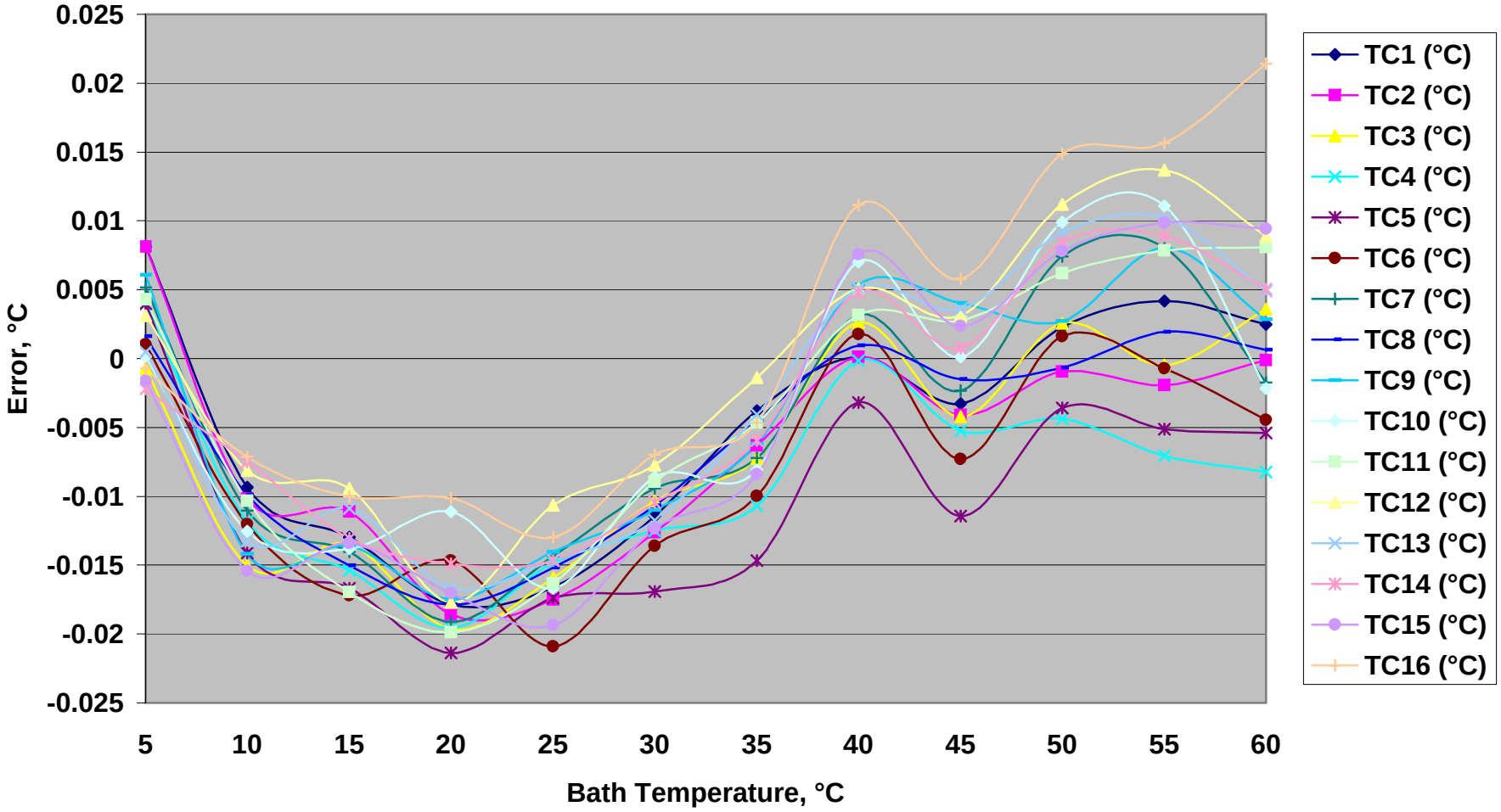
Users of our precision type T thermocouple instruments can achieve similar measurement accuracies with different thermocouples at their location by using the simple two point calibration procedure within our PPM software that accompanies each instrument – provided they have a way to measure temperatures accurately. Calibration of the instrument and thermocouples at two points in a stable bath or thermos at two known temperatures enables the user to achieve measurement accuracies similar to those shown on the following pages.

Some customers order a highly accurate and stable thermistor probe or RTD probe attached to their thermocouple instrument at the time of purchase, for use as a precision temperature standard and for use in calibrating their thermocouples.

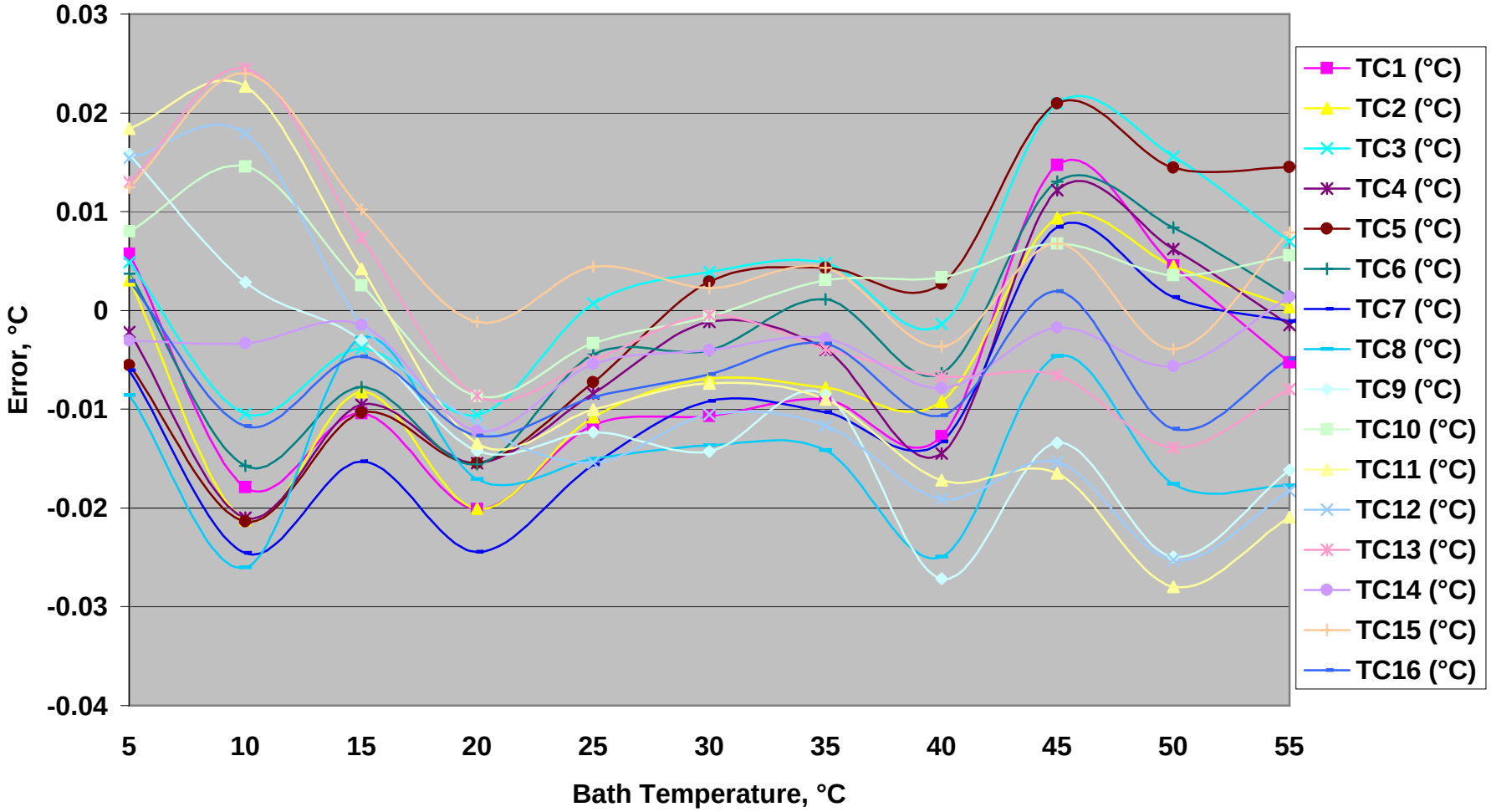
We can also produce instrumentation to achieve high accuracies in temperature measurements with thermocouples, at much higher and lower temperatures, and with other thermocouple types, through use of the same techniques discussed here.

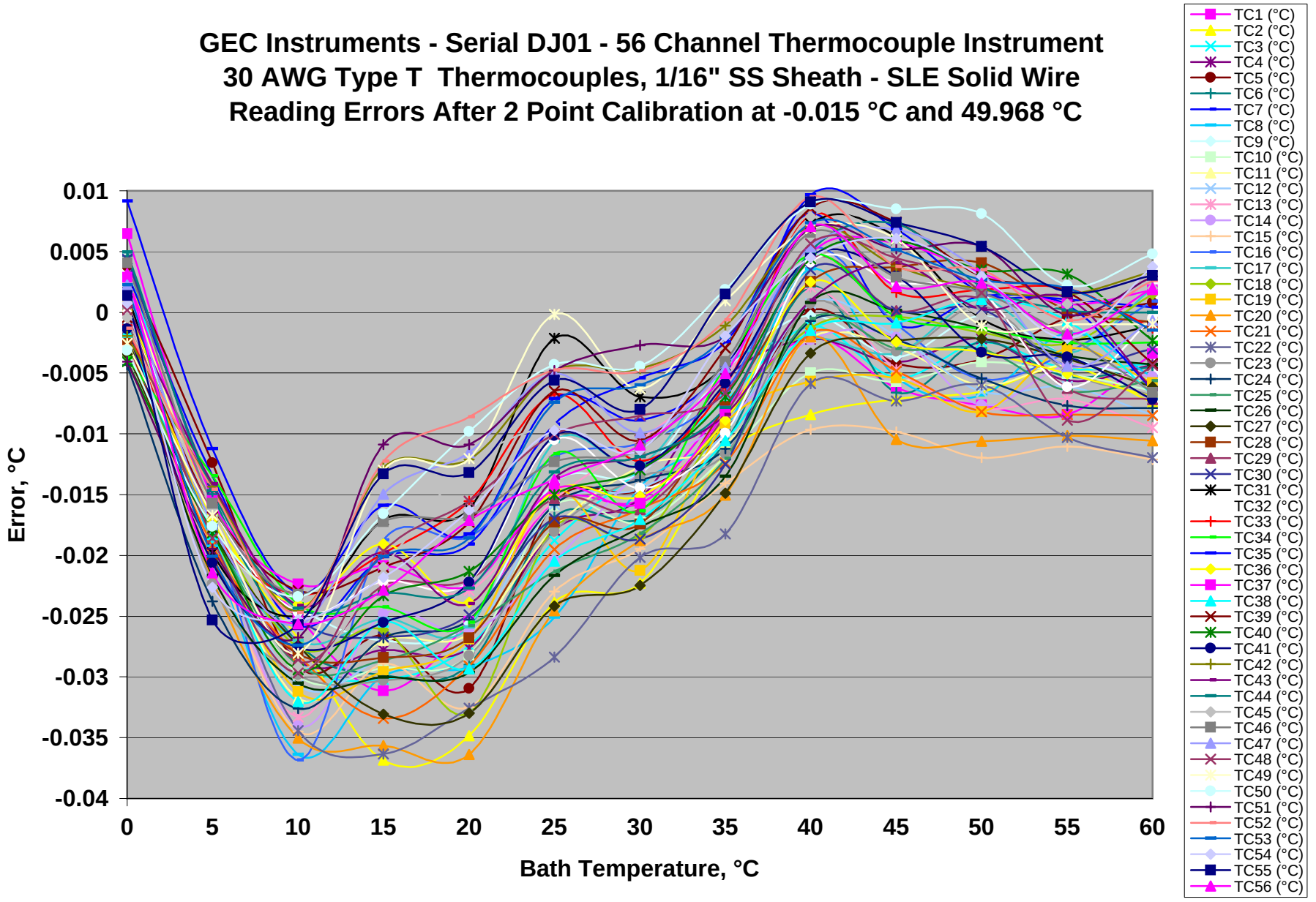

GEC Instruments - Model S4TC, Serial CA01 Thermocouple Instrument
36 AWG Type T Thermocouples - SLE Solid Wire
Reading Errors After 2 Point Calibration at 0.148 °C and 51.708 °C
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
Error, °C
0
5
10
15
20
25
30
35
40
45
50
55
60
Bath Temperature, °C
TC1 (°C)
TC2 (°C)
TC3 (°C)
TC4 (°C)

GEC Instruments - CD01 Precision Thermocouple Instrument
24 AWG Type T Thermocouples - SLE Stranded Wire
Reading Errors After 2 Point Calibration at 5 °C and 40 °C



GEC Instruments - CF01 Precision Thermocouple Instrument
36 AWG Type T Thermocouples - SLE Solid Wire
Reading Errors After 2 Point Calibration at 15 °C and 45 °C




GEC Instruments - Serial DJ01 - 56 Channel Thermocouple Instrument
30 AWG Type T Thermocouples, 1/16" SS Sheath - SLE Solid Wire
Reading Errors After 2 Point Calibration at -0.015 °C and 49.968 °C
Error, °C
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
0
5
10
15
20
25
30
35
40
45
50
55
60
Bath Temperature, °C
TC1 (°C)
TC2 (°C)
TC3 (°C)
TC4 (°C)
TC5 (°C)
TC6 (°C)
TC7 (°C)
TC8 (°C)
TC9 (°C)
TC10 (°C)
TC11 (°C)
TC12 (°C)
TC13 (°C)
TC14 (°C)
TC15 (°C)
TC16 (°C)
TC17 (°C)
TC18 (°C)
TC19 (°C)
TC20 (°C)
TC21 (°C)
TC22 (°C)
TC23 (°C)
TC24 (°C)
TC25 (°C)
TC26 (°C)
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TC36 (°C)
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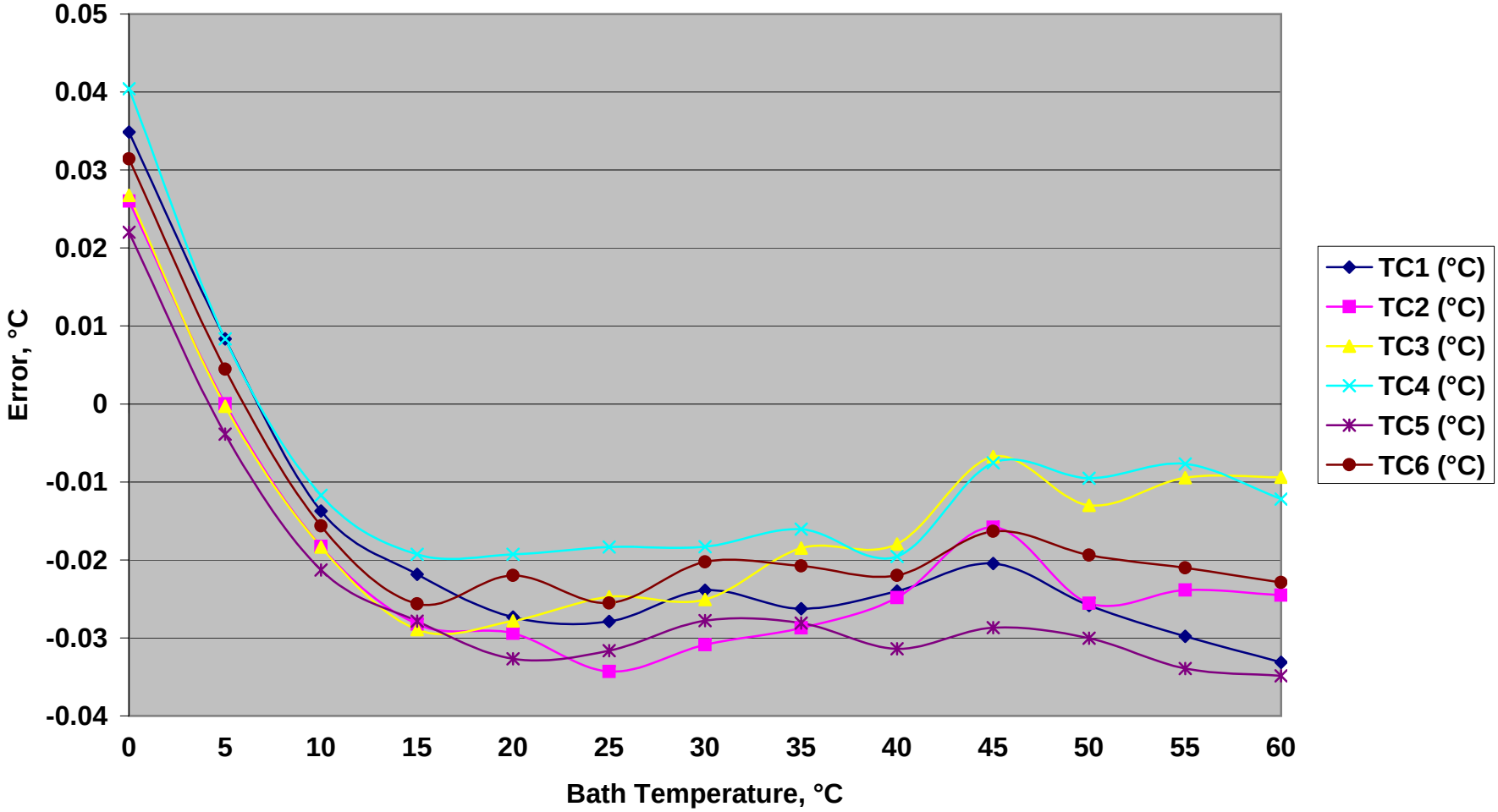
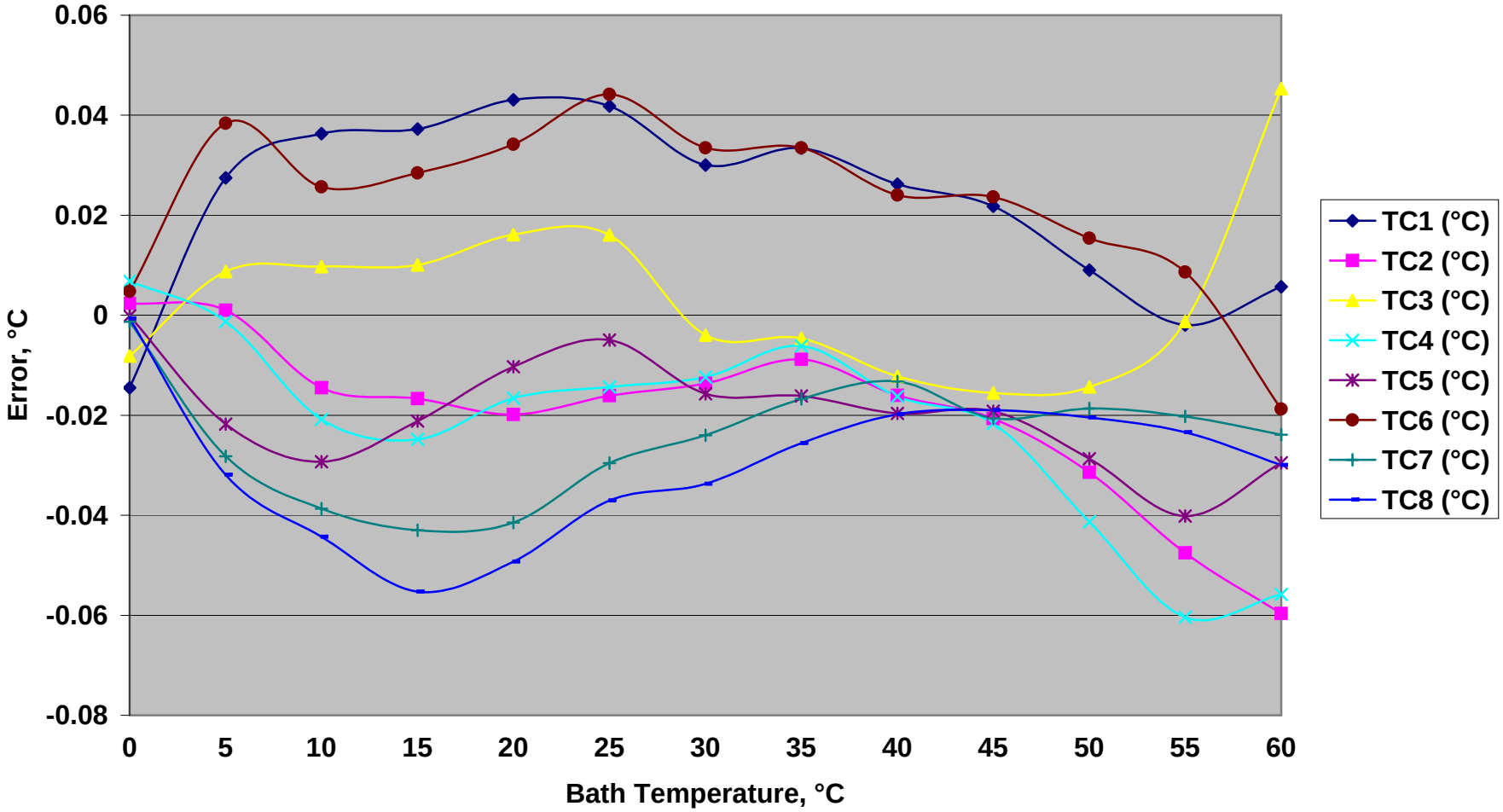
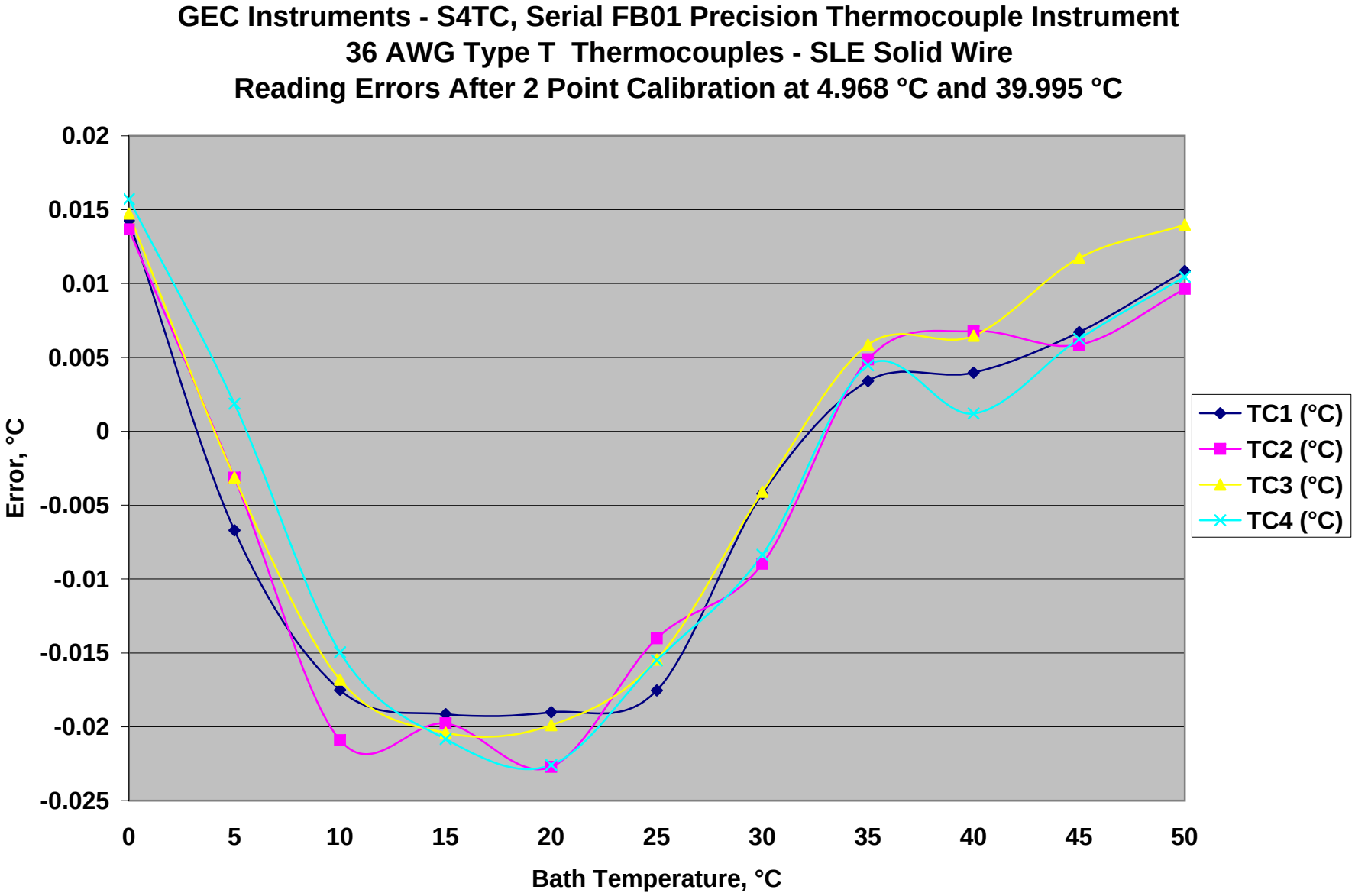
TC40 (°C)
TC41 (°C)
TC42 (°C)
TC43 (°C)
TC44 (°C)
TC45 (°C)
TC46 (°C)
TC47 (°C)
TC48 (°C)
TC49 (°C)
TC50 (°C)
TC51 (°C)
TC52 (°C)
TC53 (°C)
TC54 (°C)
TC55 (°C)
TC56 (°C)

GEC Instruments - ED01 6 Channel Precision Thermocouple Instrument
36 AWG Type T Thermocouples - SLE Solid Wire
Reading Errors after 2 Point Calibration at 5 °C and 45 °C



GEC Instruments - Serial EL01 Precision Thermocouple Instrument
24 AWG Type T Unmatched Probes, 1/8" Sheath - Customer Supplied
Reading Errors After 2 Point Calibration at -0.009 °C and 54.697 °C




GEC Instruments - S4TC, Serial FB01 Precision Thermocouple Instrument
36 AWG Type T Thermocouples - SLE Solid Wire
Reading Errors After 2 Point Calibration at 4.968 °C and 39.995 °C
Error, °C
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
0
5
10
15
20
25
30
35
40
45
50
Bath Temperature, °C
TC1 (°C)
TC2 (°C)
TC3 (°C)
TC4 (°C)