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Achieving Ultra High Accuracy in Temperature Measurements With Thermocouples by Calibration of Thermocouple Wire at Multiple Points

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A previous document "Achieving Ultra High Accuracy in Temperature Measurements With Thermocouples", June 2008, described instrumentation and methods developed by GEC Instruments to achieve high accuracy in temperature measurements with type T thermocouples in multiple channel instruments. This included highly accurate voltage measurement, and a propriety reference junction system internal to the instrument with reference junction error of 0.005 °C or less on all channels. That instrumentation used the standard NIST reference function for type T, followed by a 2 point calibration of all thermocouples against a precision reference thermometer in a stable liquid bath at the end points of the range of interest. Supporting data from 8 different type T thermocouple instruments, manufactured and calibrated at GEC, showed errors of ± 0.04 °C or less on all channels over the range 0 °C to 60 °C.

Because the deviation of thermocouple EMF from the standard reference functions is typically nonlinear with temperature, a 2 point calibration yields good results at the end points of the calibration but less accuracy at intermediate points.

More recently we have developed a system with a new reference junction measurement accurate to ± 0.003 °C, and involving multiple point calibration over the range of interest. For multiple channel instruments, all thermocouples for that instrument are obtained from the same lot or same roll of thermocouple wire. We begin by taking a single sample of that wire and we measure the EMF output at multiple temperatures with the thermocouple in a stable liquid bath and with the reference junction at 0 °C.

An example of thermocouple wire deviation from the standard NIST ITS-90 reference function for type T, obtained from such measurements, is shown on page 3.

We use the EMF versus temperature data obtained from our precision measurements to develop polynomial coefficients for a reference function (temperature to microvolts) and additional polynomial coefficients for an inverse function (microvolts to temperature) representing that particular wire. An example of the forward reference function is shown on page 4, and the inverse function for the same wire is shown on page 5. Note that these curves are very smooth and are more easily modeled than are the deviations from the NIST function as shown on page 3.

Page 6 shows the residuals from the regressions on the temperature versus EMF data. These residuals represent how well the coefficients from the regressions represent the original data. With our type T instrumentation, the residuals are typically within ± 0.005 ° C and arise from the noise in the measurement system which is the same as the effective resolution of our measurements.

The coefficients for the reference function, and for the inverse function, developed for that single piece of wire are then embedded in the configuration file for the instrument. Then we do a 2 point calibration on all thermocouples in the instrument against a precision reference thermometer in a stable liquid bath at the end points of the range of interest.

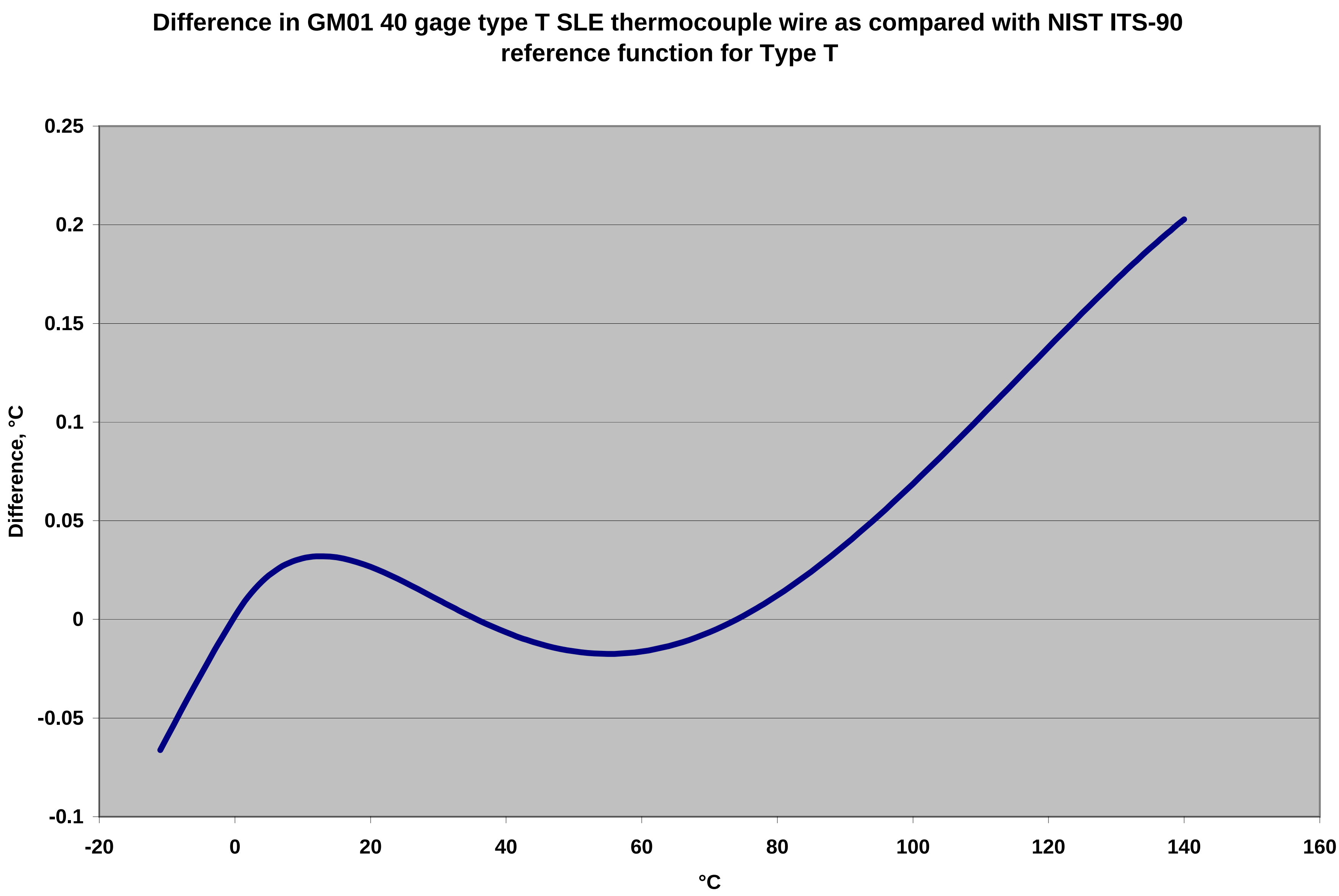
Data from 14 different instruments using the above described procedures, with channel counts ranging from 4 to 94 channels in the same instrument, and calibration temperatures ranging from -10 to 140 °C are shown on pages 7 to 20. Note the high accuracy and the excellent channel to channel uniformity over the entire temperature range for each of these instruments. The error given is the difference from the reference thermometer reading. The estimated uncertainty of the reference thermometer reading was 0.002 °C over -10 °C to 30 °C, 0.004 °C over 35 to 60 °C, and 0.01 °C over 65 °C to 140 °C.

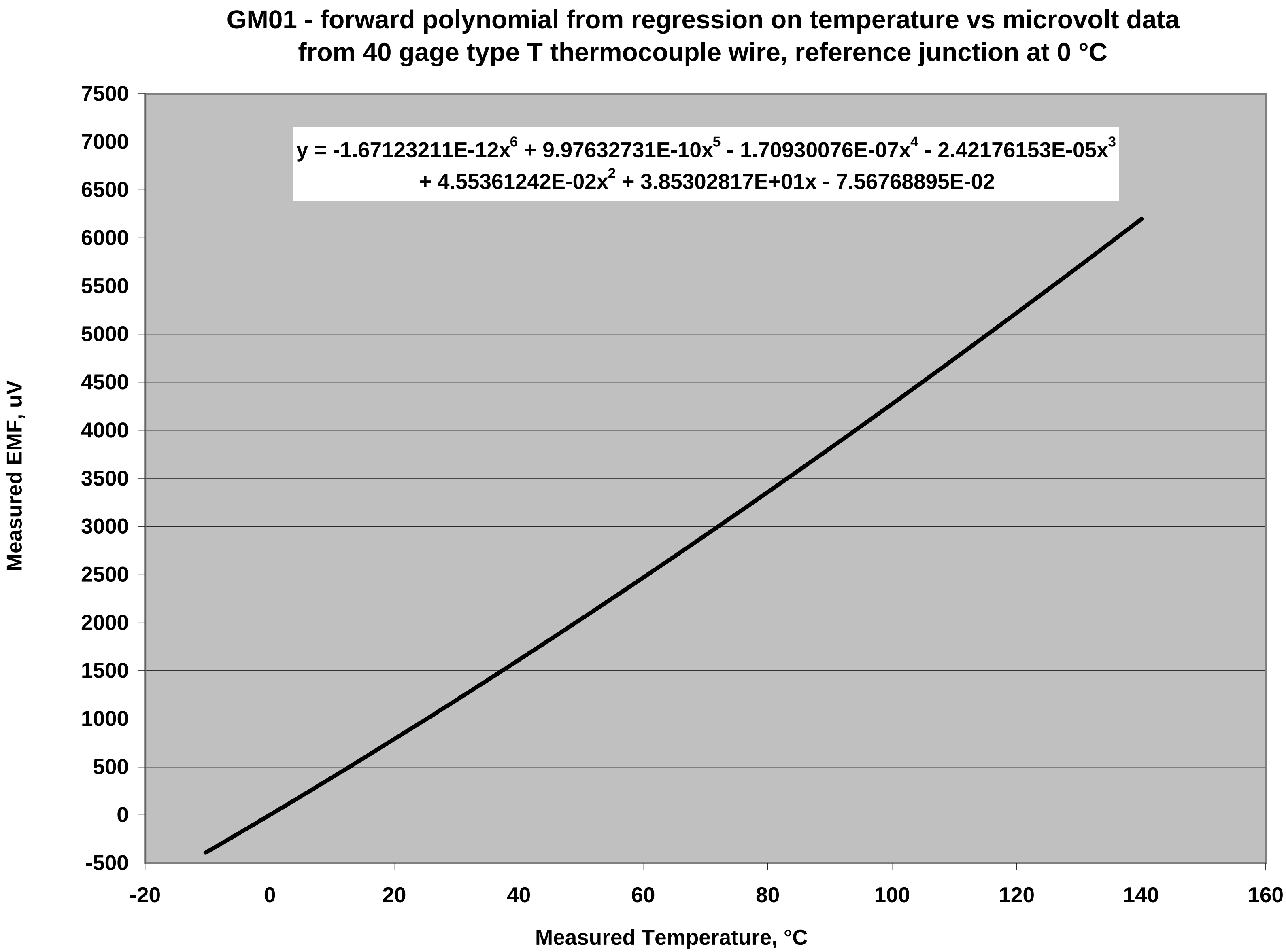
All instruments are type T, except for GE05 on page 10 which involved calibration of type E thermocouple wire.

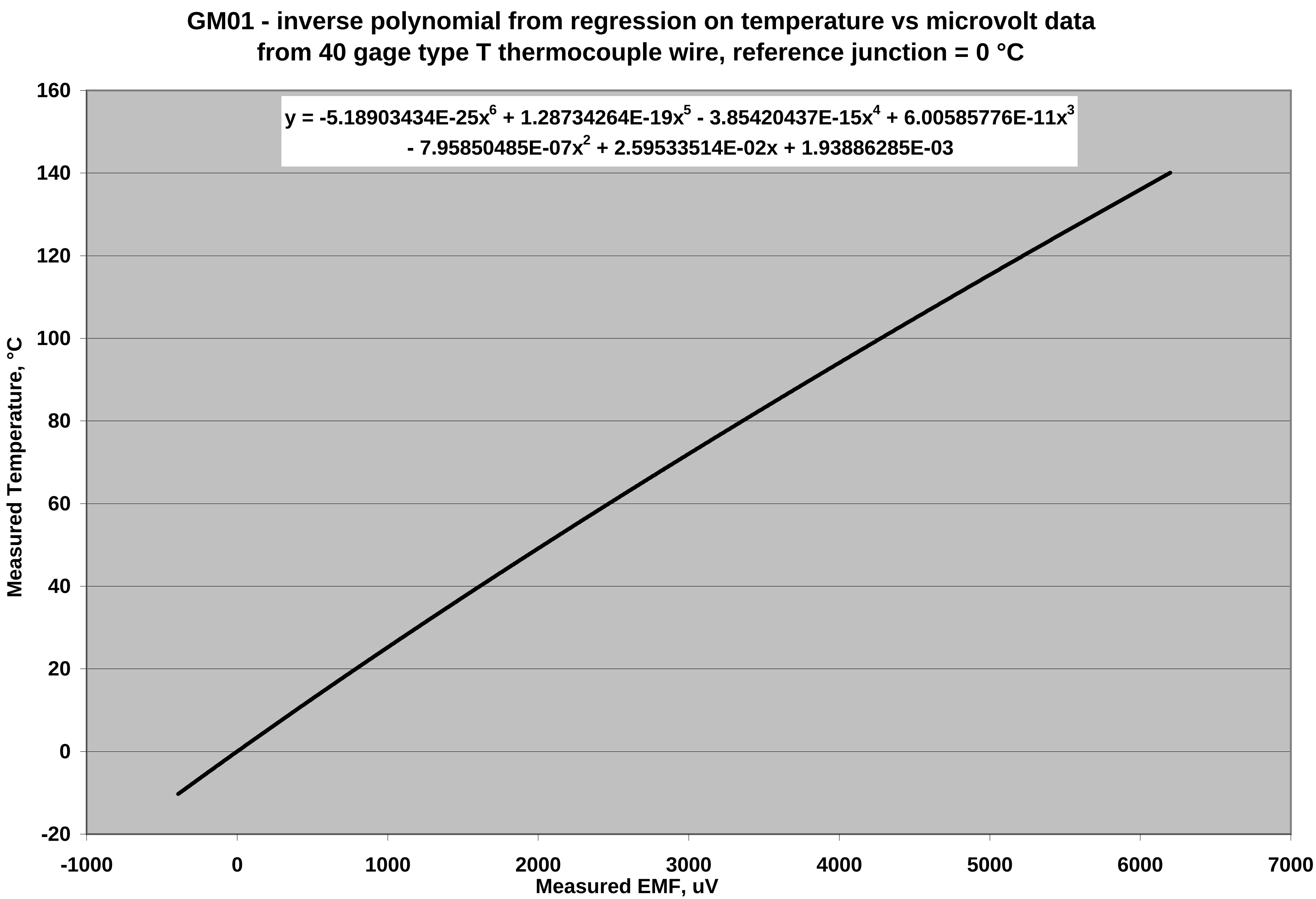
Note that instruments GE01, page 8, and GE03 page 9, each have 94 thermocouples 25' long. Those thermocouples all came from a single lot of 24 gage type T wire, originally 10,000 feet in length, and the temperature versus EMF data used in those instruments was from a single piece of wire from this lot.

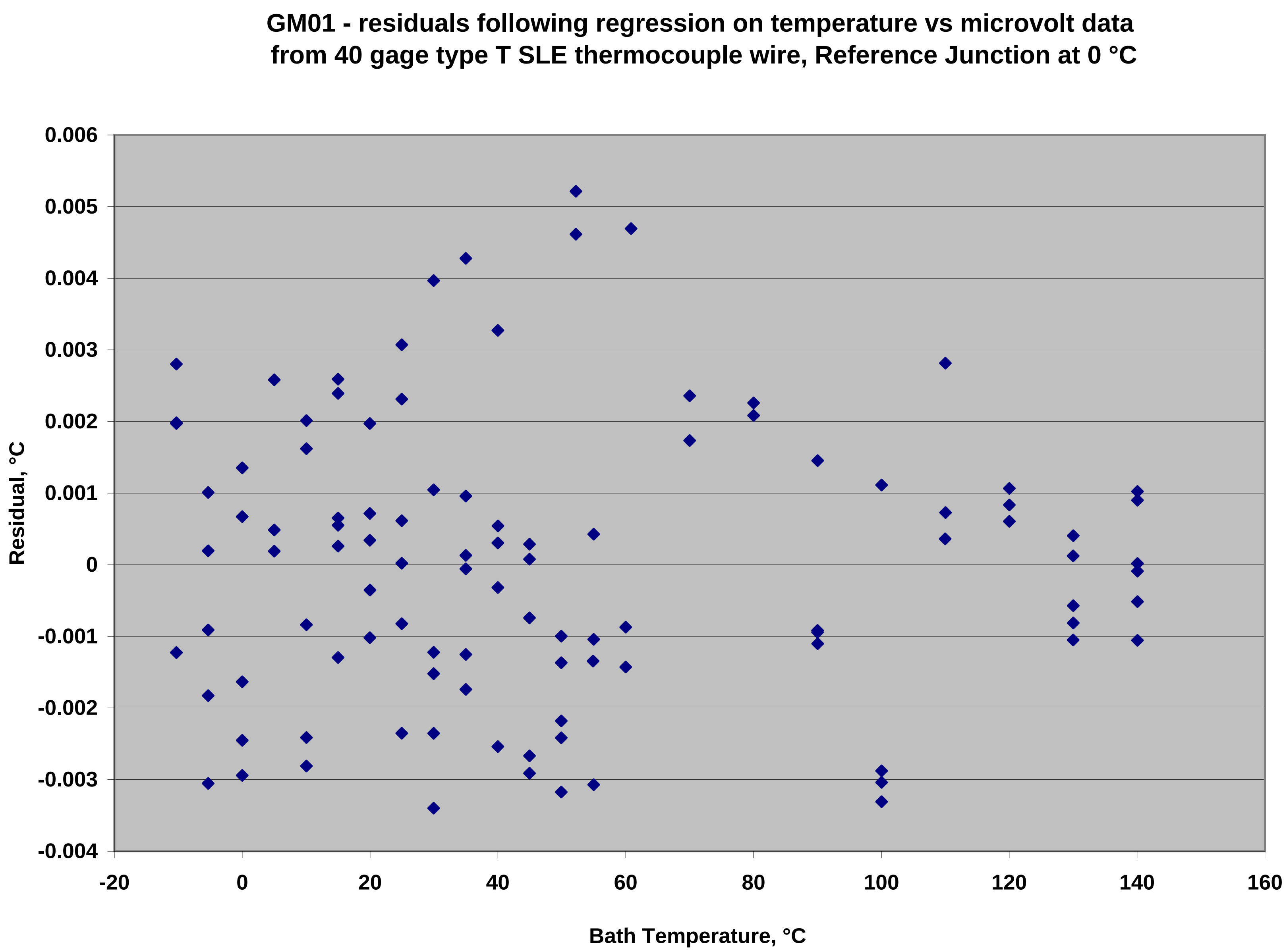
For instruments JE01, KJ01, KJ02, and LB01, we did not obtain calibration data on the actual wire that was used for those instruments. Rather, for each of those instruments, we used the calibration coefficients for the 36 gage type T wire used in instrument HK02 and then did a two point calibration at the high and low end points. The actual wire used for instruments JE01, KJ01, KJ02, and LB01 was of different gage than the wire in HK02. And the wire was from two different manufacturers, both different than the wire in use in HK02. Even so, the data for instruments JE01, KJ01, KJ02, and LB01 show excellent results, indicating that our coefficients for the wire used in HK02 much better represent the shape of the temperature versus EMF relation for completely different samples of type T wire than do the standard NIST reference functions for type T.

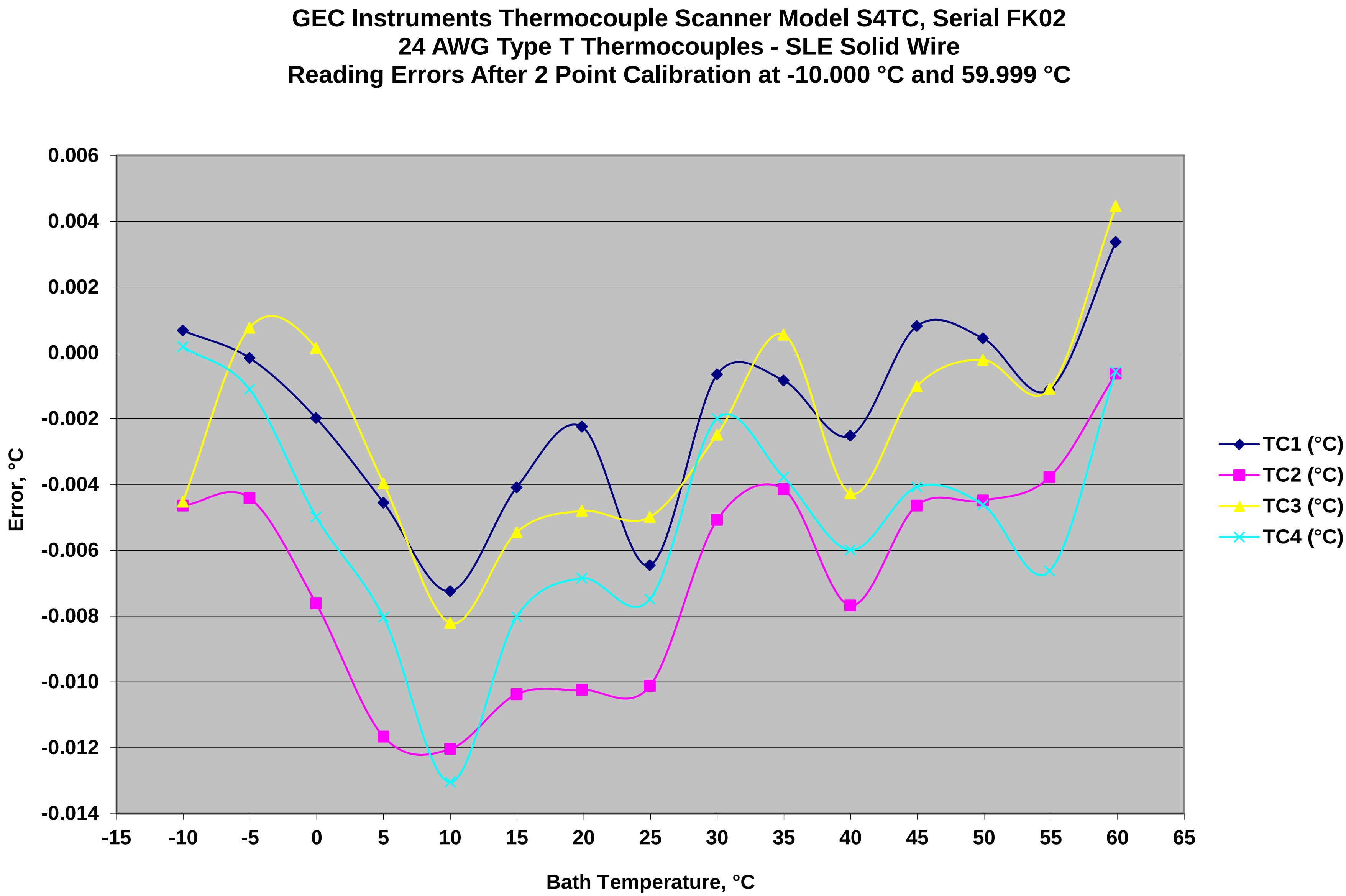
For those customers that have GEC thermocouple instrumentation, and wish to develop the temperature versus EMF data for the wire they are using, we have developed a software application called TCCONFIG that can be used to insert coefficients for calibrated thermocouples into the software configuration file for their instrument. A description of that procedure is given in the document New GEC Thermocouple Techniques available at www.gecinstruments.com.


Difference in GM01 40 gage type T SLE thermocouple wire as compared with NIST ITS-90 reference function for Type T
Difference, °C
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-20
0
20
40
60
80
100
120
140
160
°C

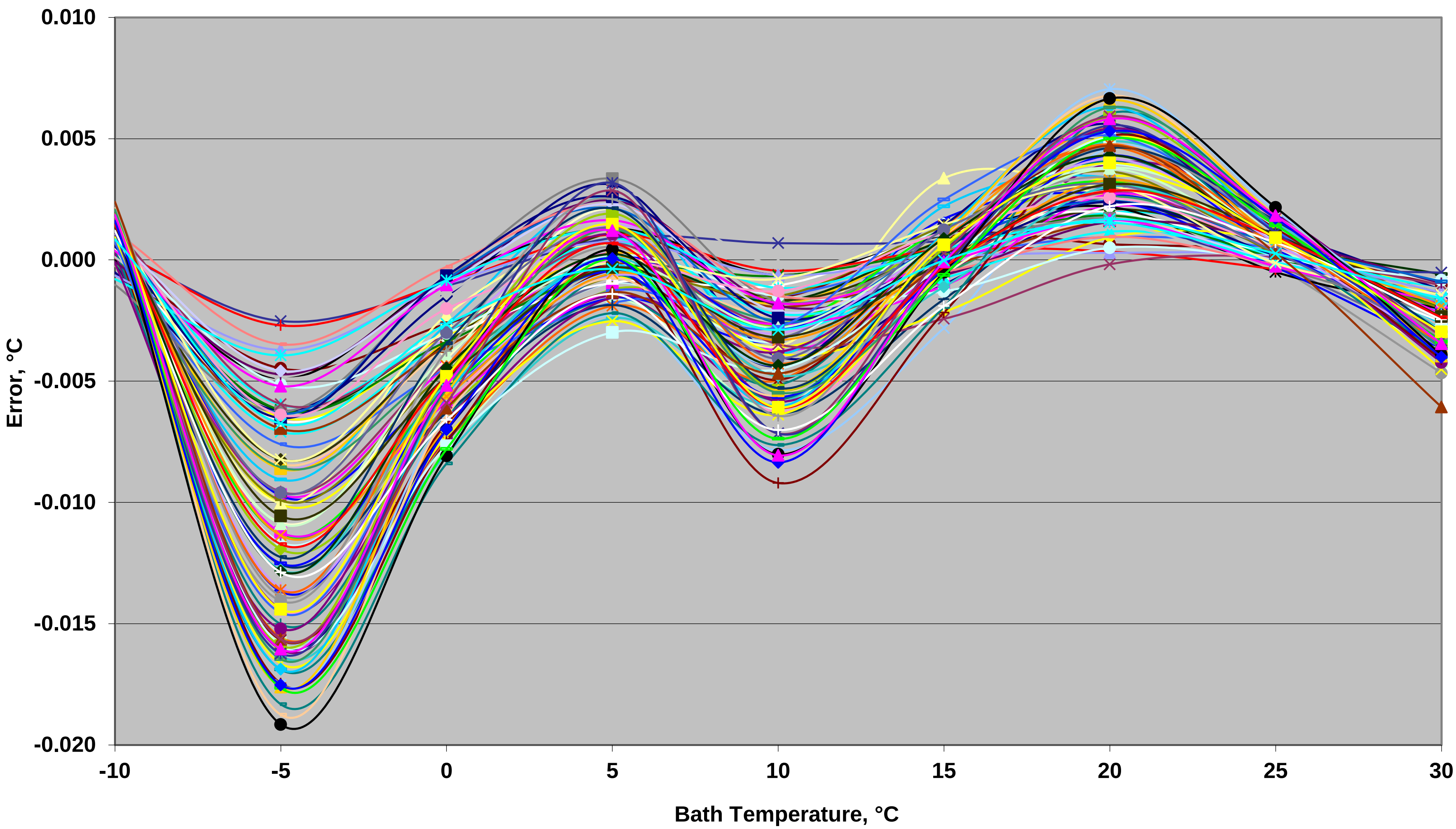

GM01 - forward polynomial from regression on temperature vs microvolt data
from 40 gage type T thermocouple wire, reference junction at 0 °C
y = -1.67123211E-12x6 + 9.97632731E-10x5 - 1.70930076E-07x4 - 2.42176153E-05x3
+ 4.55361242E-02x2 + 3.85302817E+01x - 7.56768895E-02
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
Measured EMF, uV
-20
0
20
40
60
80
100
120
140
160
Measured Temperature, °C

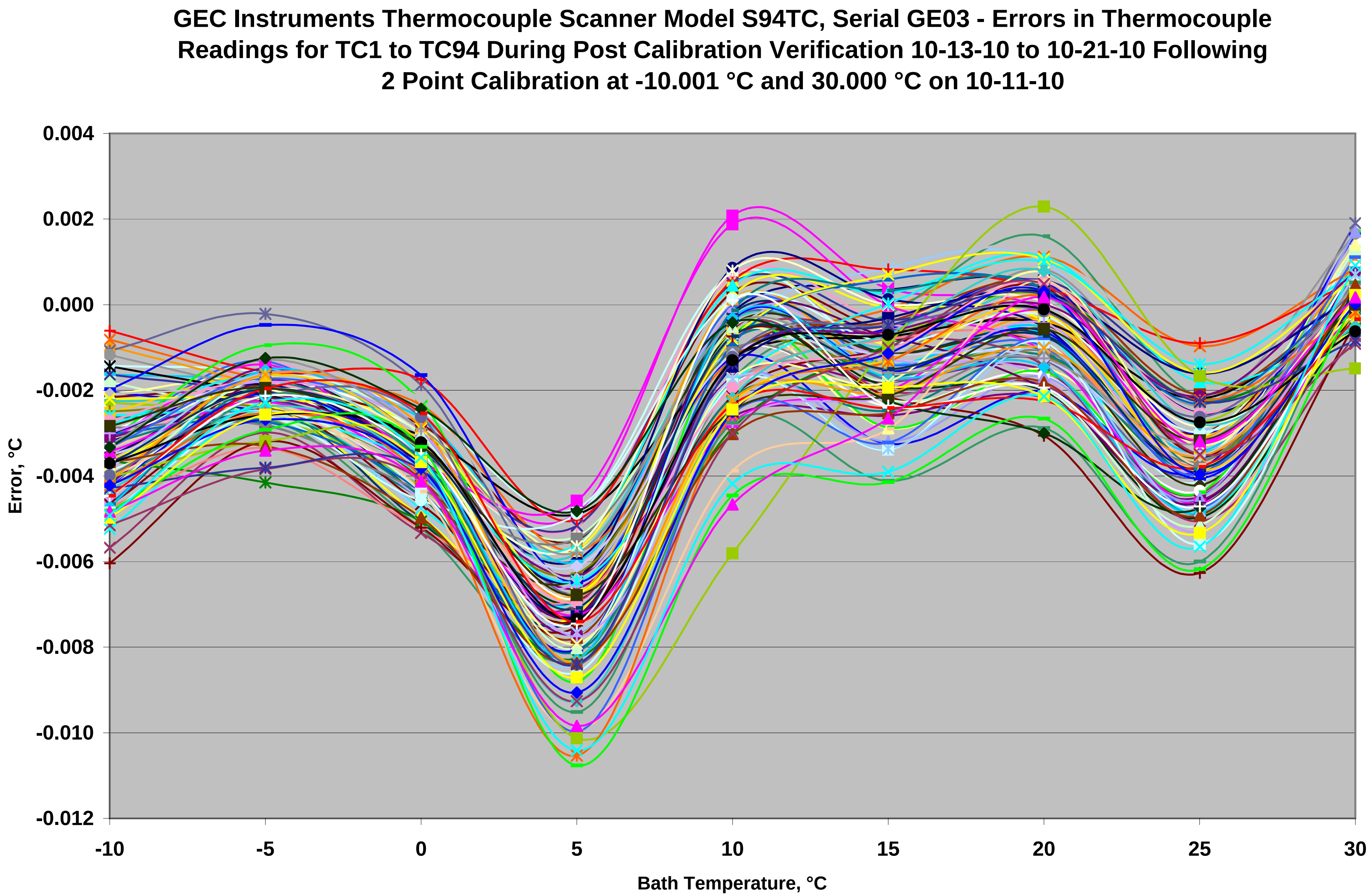

GM01 - inverse polynomial from regression on temperature vs microvolt data
from 40 gage type T thermocouple wire, reference junction = 0 °C
y = -5.18903434E-25x6 + 1.28734264E-19x5 - 3.85420437E-15x4 + 6.00585776E-11x3
- 7.95850485E-07x2 + 2.59533514E-02x + 1.93886285E-03
Measured Temperature, °C
Measured EMF, uV
160
140
120
100
80
60
40
20
0
-20
-1000
0
1000
2000
3000
4000
5000
6000
7000

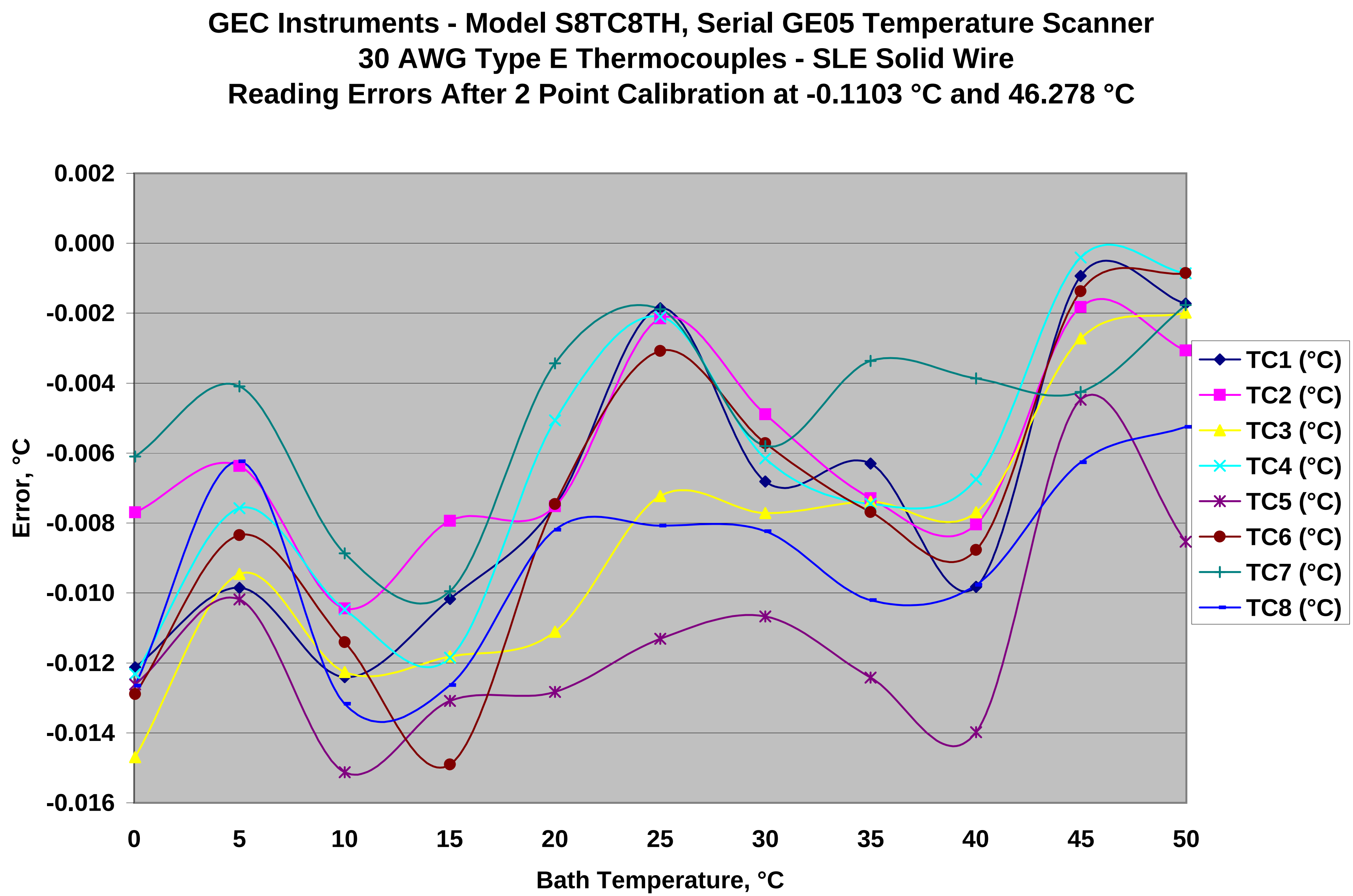

GM01 - residuals following regression on temperature vs microvolt data
from 40 gage type T SLE thermocouple wire, Reference Junction at 0 °C
Residual, °C
0.006
0.005
0.004
0.003
0.002
0.001
0
-0.001
-0.002
-0.003
-0.004
-20
0
20
40
60
80
100
120
140
160
Bath Temperature, °C

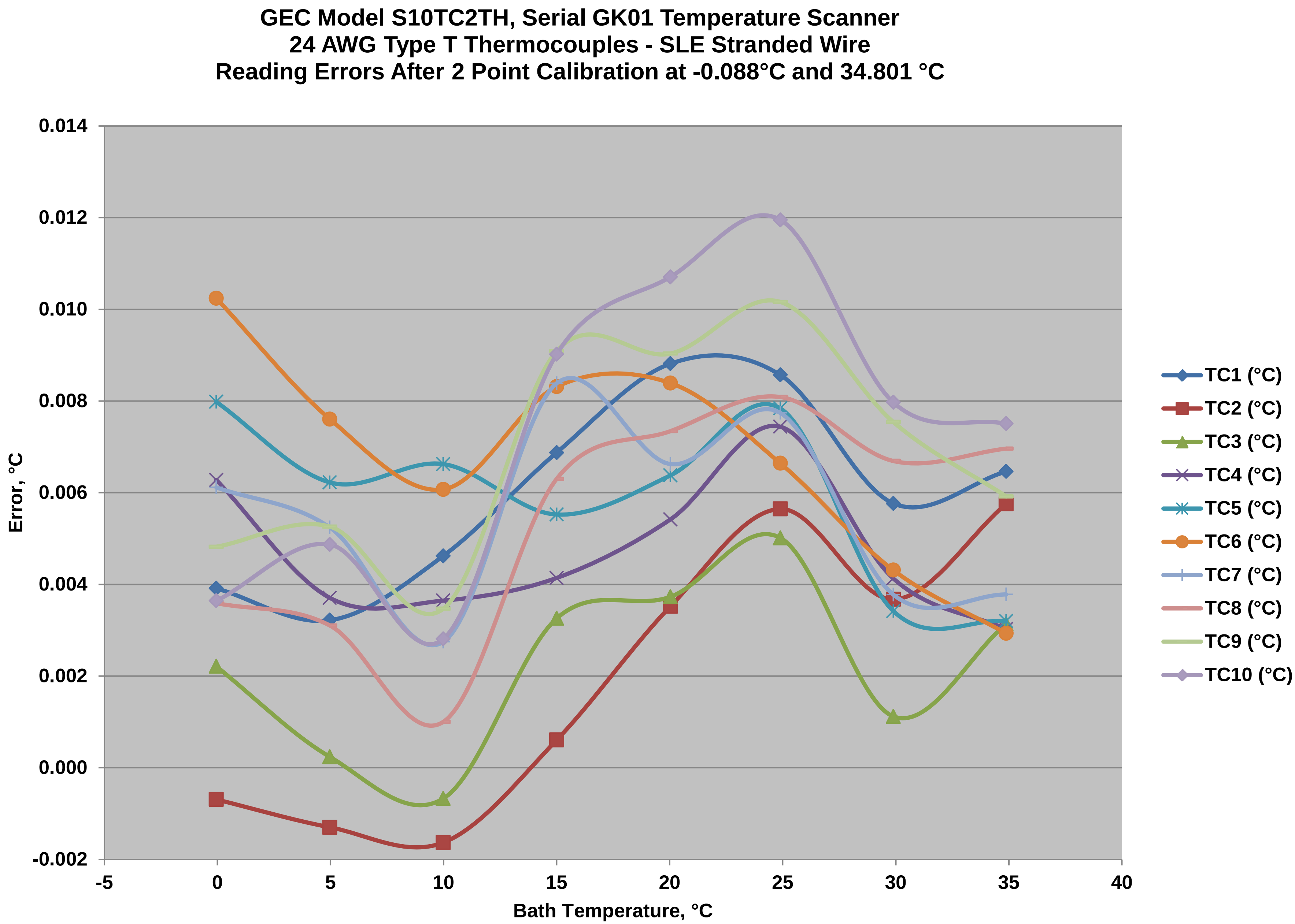

GEC Instruments Thermocouple Scanner Model S4TC, Serial FK02
24 AWG Type T Thermocouples - SLE Solid Wire
Reading Errors After 2 Point Calibration at -10.000 °C and 59.999 °C
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-0.012
-0.014
Error, °C
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Bath Temperature, °C
TC1 (°C)
TC2 (°C)
TC3 (°C)
TC4 (°C)

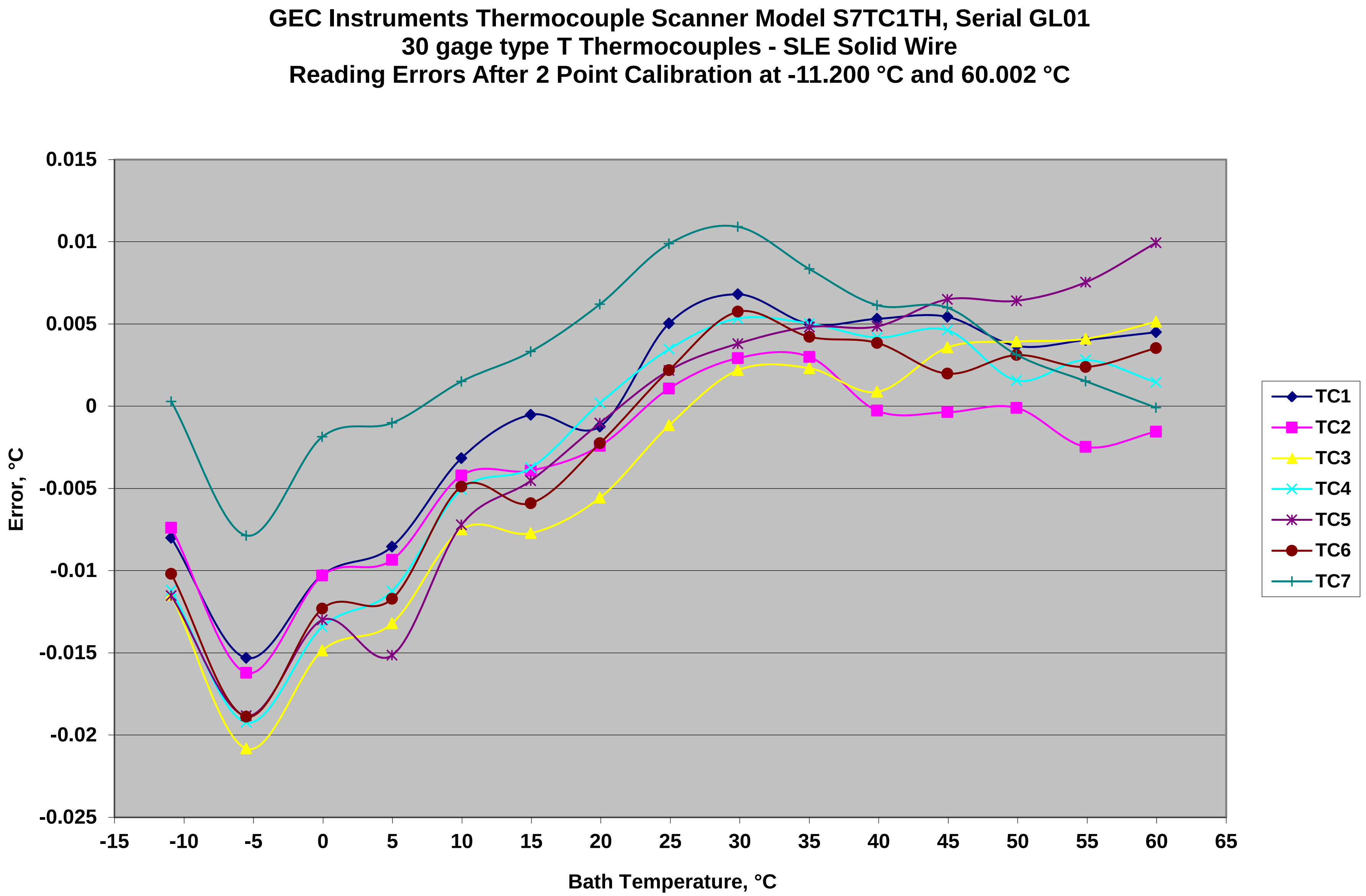
GEC Instruments Model S94TC, SN GE01 - Errors in Thermocouple Readings for TC1 to TC94 Following Calibration of a Single Wire from This Lot at 5 °C Intervals Over -10 to 35 °C, then 2 Point Calibration of all 94 Thermocouples at -10.000 °C and 30.000 °C

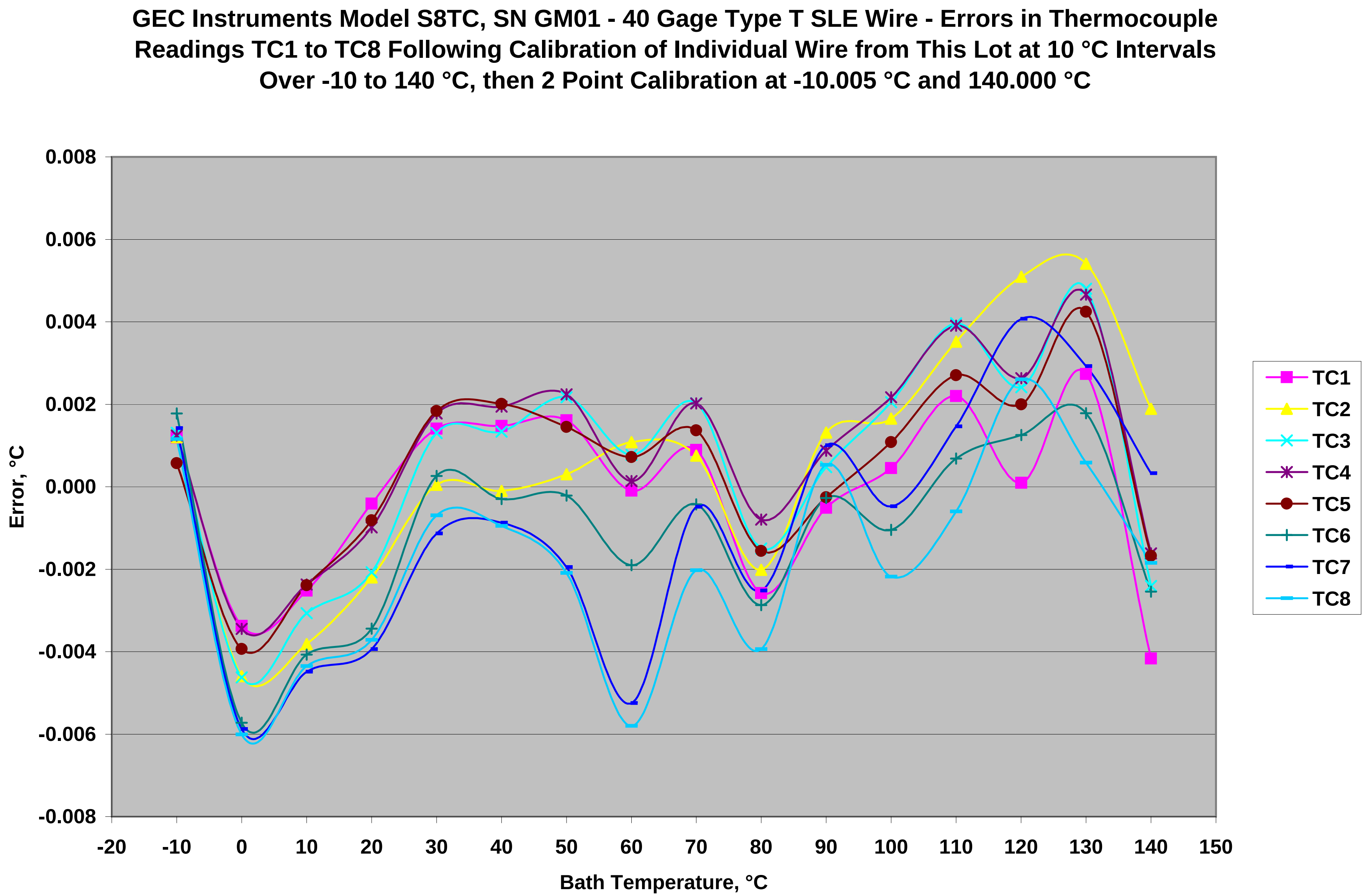



GEC Instruments Thermocouple Scanner Model S94TC, Serial GE03 - Errors in Thermocouple Readings for TC1 to TC94 During Post Calibration Verification 10-13-10 to 10-21-10 Following 2 Point Calibration at -10.001 °C and 30.000 °C on 10-11-10
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-0.012
Error, °C
-10
-5
0
5
10
15
20
25
30
Bath Temperature, °C

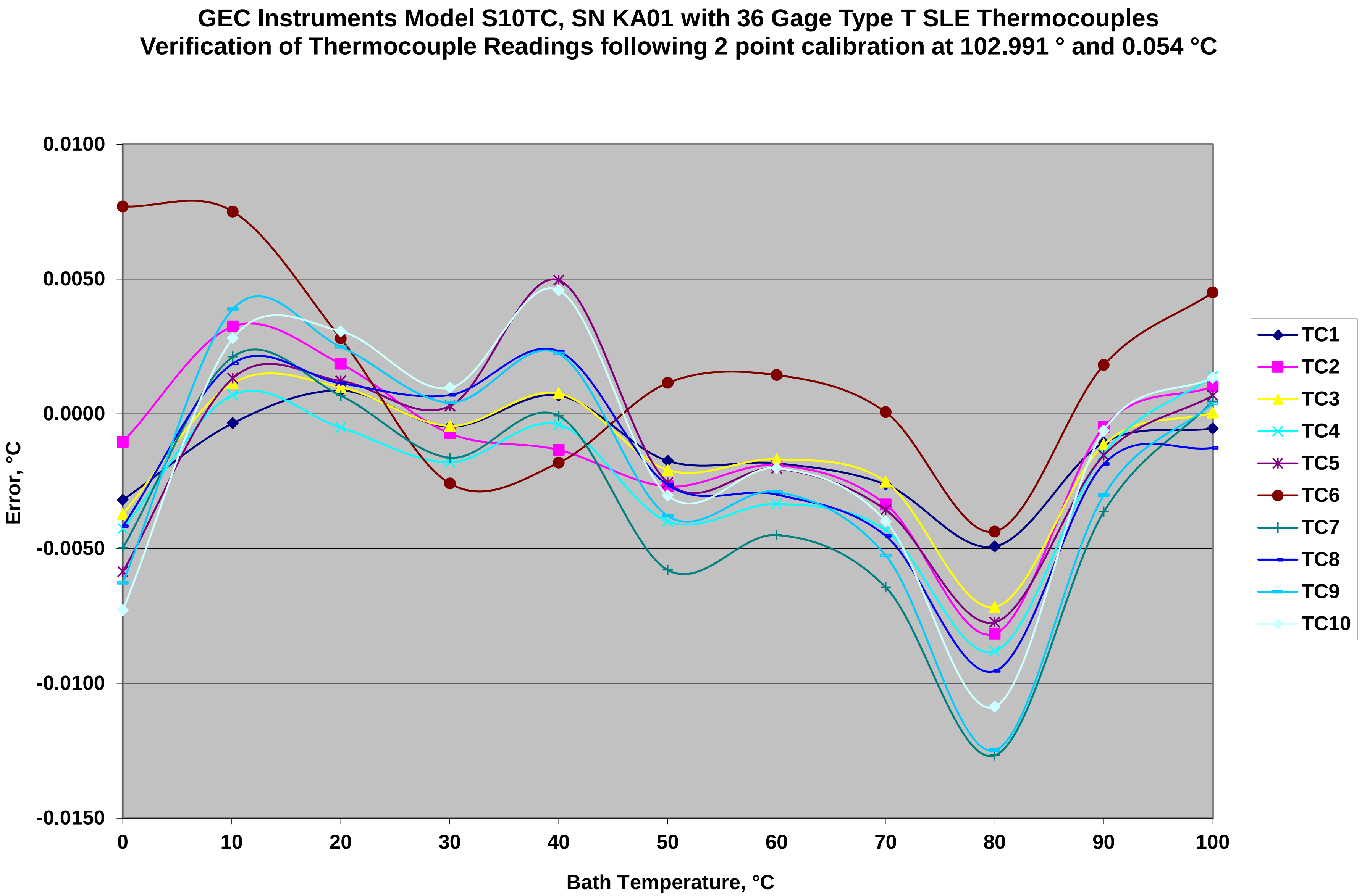

GEC Instruments - Model S8TC8TH, Serial GE05 Temperature Scanner
30 AWG Type E Thermocouples - SLE Solid Wire
Reading Errors After 2 Point Calibration at -0.1103 °C and 46.278 °C
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-0.012
-0.014
-0.016
Error, °C
0
5
10
15
20
25
30
35
40
45
50
Bath Temperature, °C
TC1 (°C)
TC2 (°C)
TC3 (°C)
TC4 (°C)
TC5 (°C)
TC6 (°C)
TC7 (°C)
TC8 (°C)

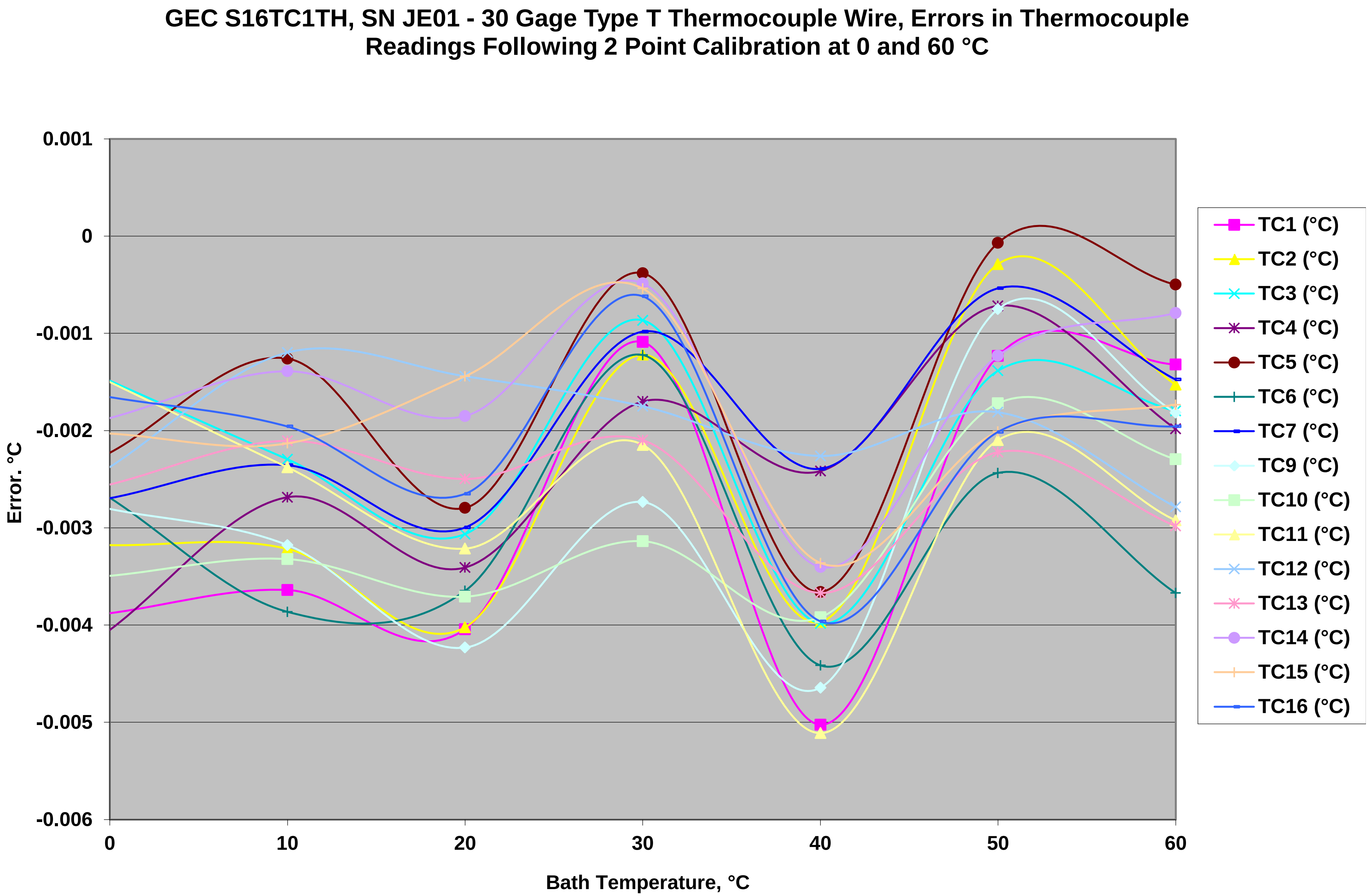

GEC Model S10TC2TH, Serial GK01 Temperature Scanner
24 AWG Type T Thermocouples - SLE Stranded Wire
Reading Errors After 2 Point Calibration at -0.088°C and 34.801 °C
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
Error, °C
-5
0
5
10
15
20
25
30
35
40
Bath Temperature, °C
TC1 (°C)
TC2 (°C)
TC3 (°C)
TC4 (°C)
TC5 (°C)
TC6 (°C)
TC7 (°C)
TC8 (°C)
TC9 (°C)
TC10 (°C)


GEC Instruments Thermocouple Scanner Model S7TC1TH, Serial GL01
30 gage type T Thermocouples - SLE Solid Wire
Reading Errors After 2 Point Calibration at -11.200 °C and 60.002 °C
Error, °C
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Bath Temperature, °C
TC1
TC2
TC3
TC4
TC5
TC6
TC7

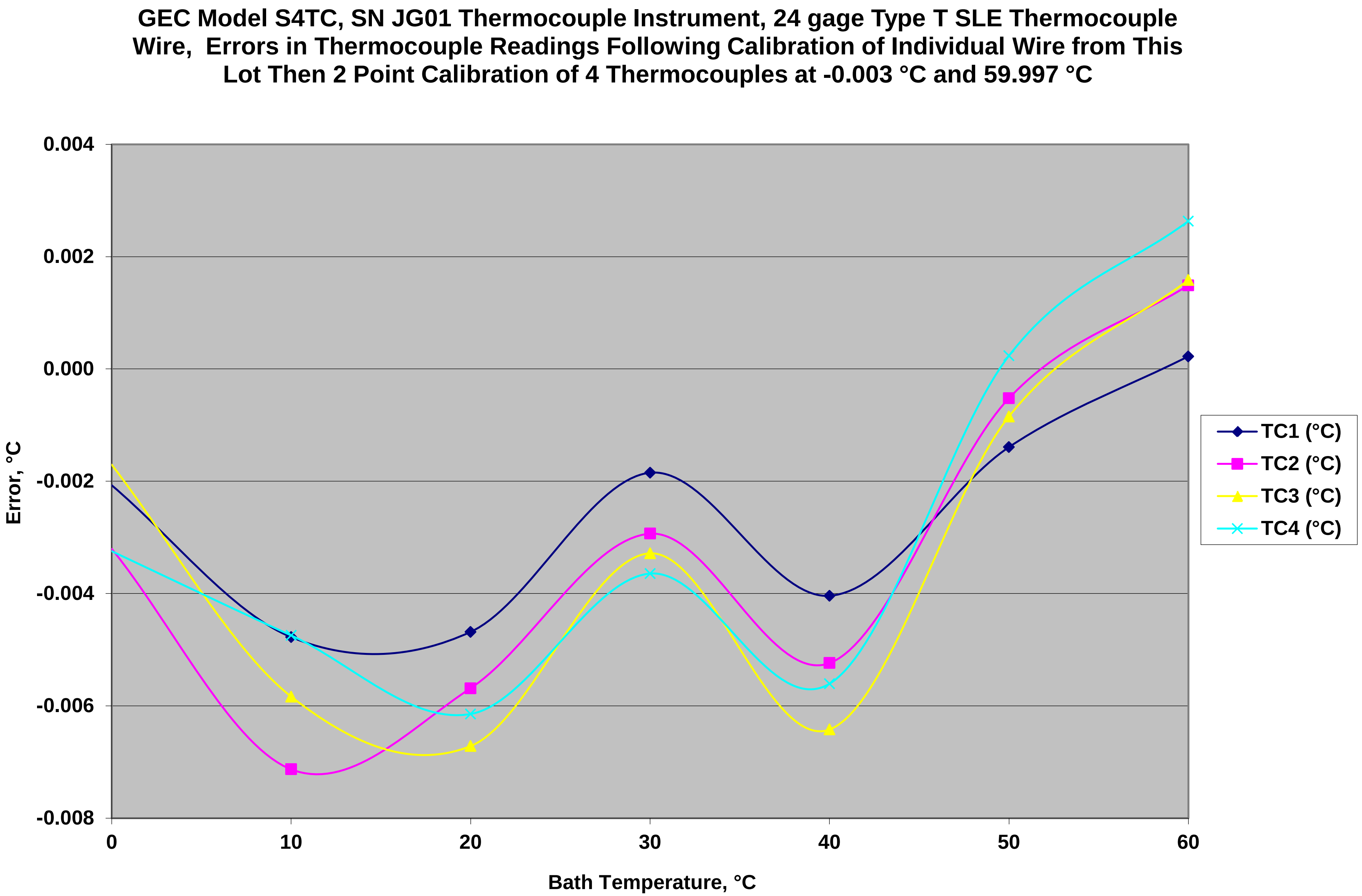


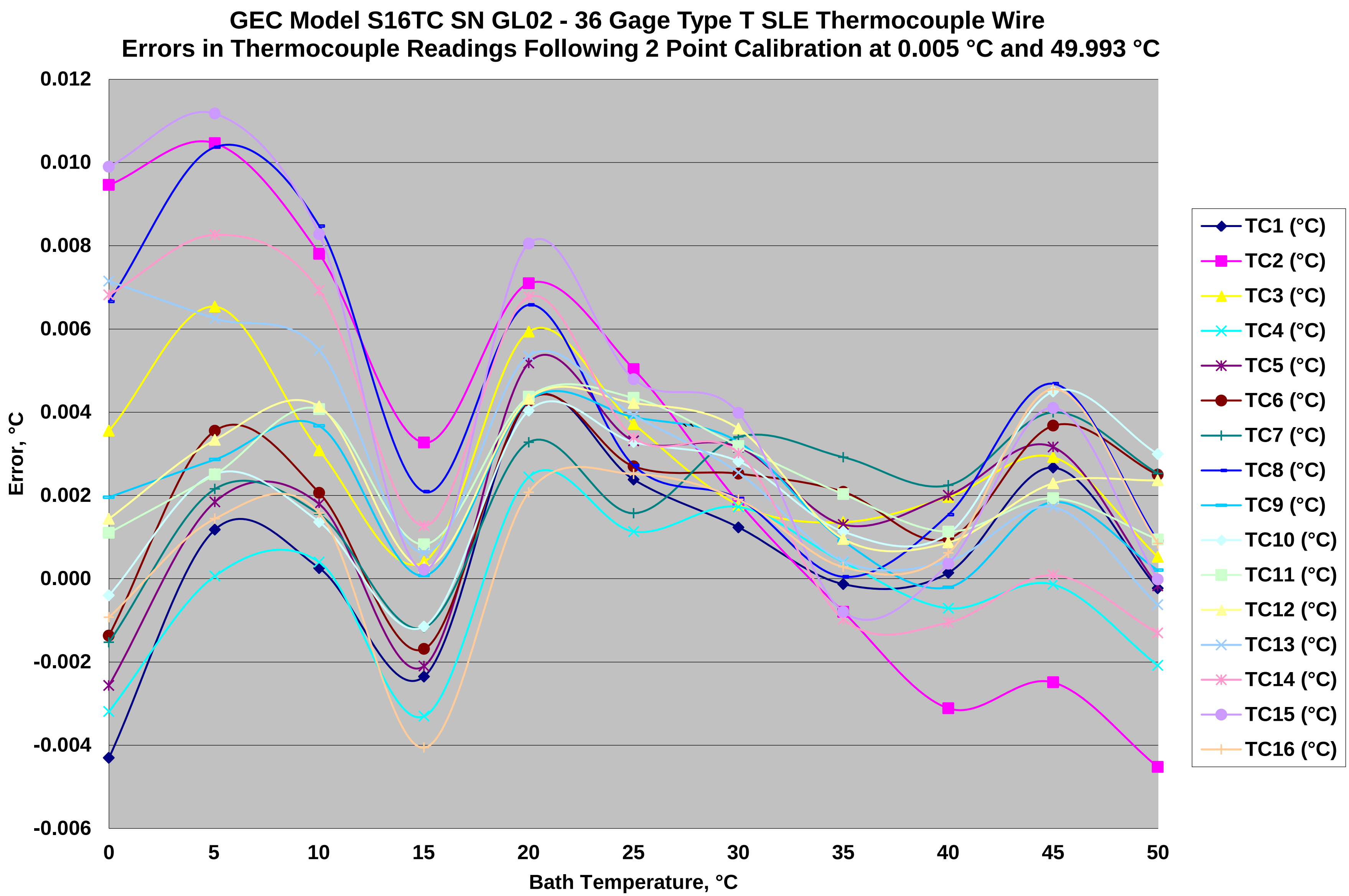
GEC Instruments Model S8TC, SN GM01 - 40 Gage Type T SLE Wire - Errors in Thermocouple Readings TC1 to TC8 Following Calibration of Individual Wire from This Lot at 10 °C Intervals Over -10 to 140 °C, then 2 Point Calibration at -10.005 °C and 140.000 °C
Error, °C
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Bath Temperature, °C
TC1
TC2
TC3
TC4
TC5
TC6
TC7
TC8


GEC Instruments Model S10TC, SN KA01 with 36 Gage Type T SLE Thermocouples
Verification of Thermocouple Readings following 2 point calibration at 102.991 ° and 0.054 °C
Error, °C
0.0100
0.0050
0.0000
-0.0050
-0.0100
-0.0150
0
10
20
30
40
50
60
70
80
90
100
Bath Temperature, °C
TC1
TC2
TC3
TC4
TC5
TC6
TC7
TC8
TC9
TC10

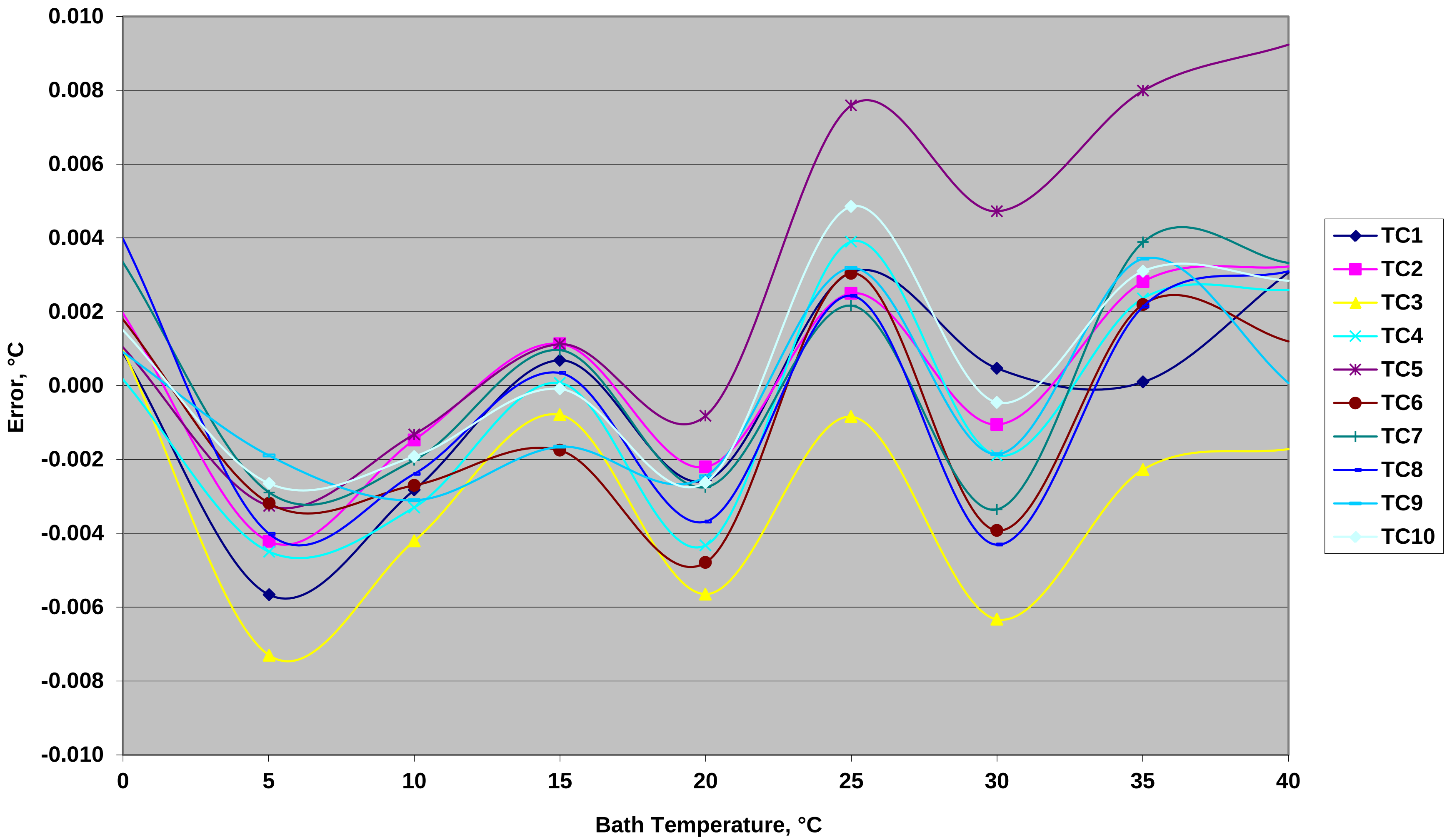


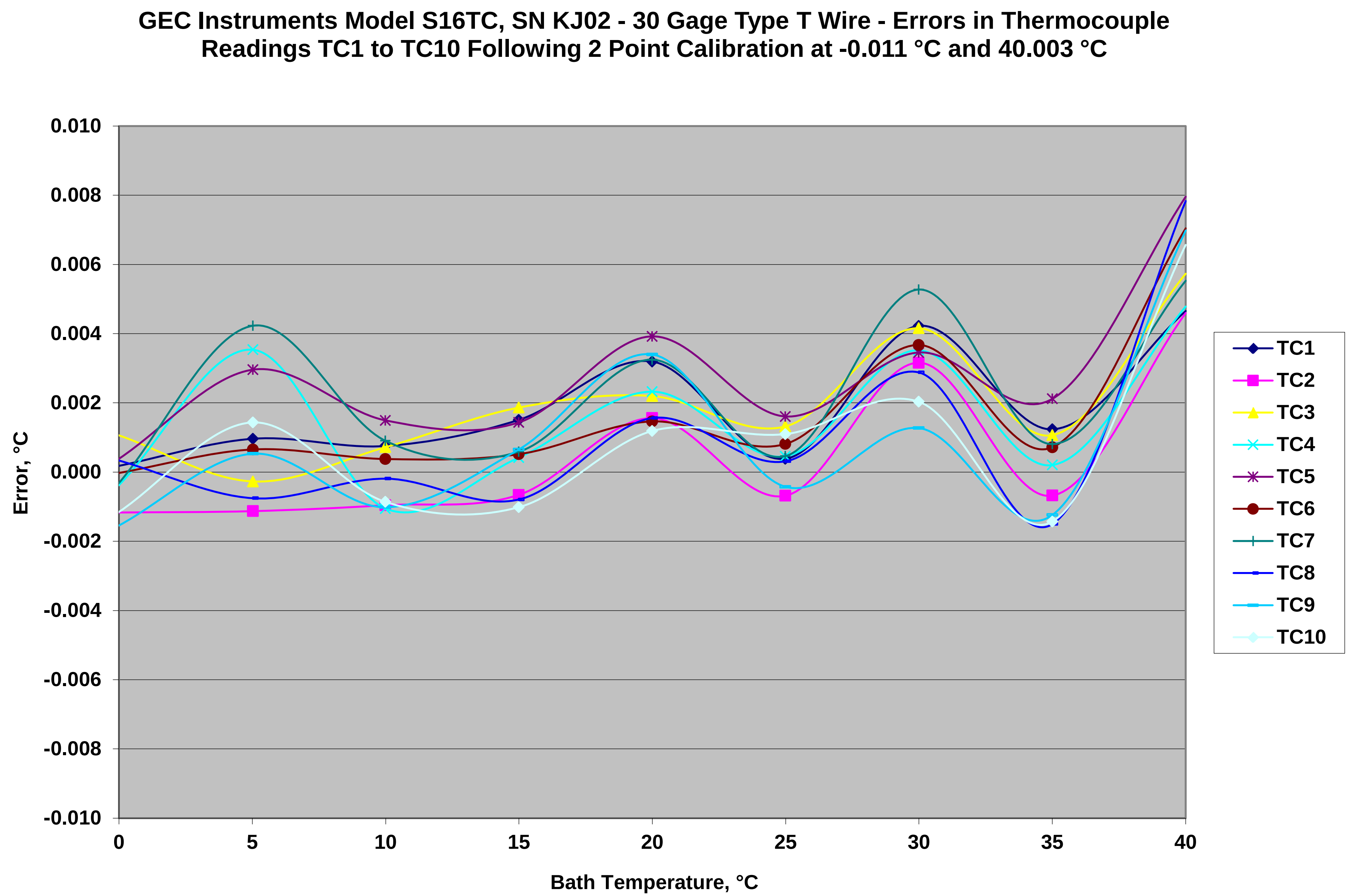
GEC S16TC1TH, SN JE01 - 30 Gage Type T Thermocouple Wire, Errors in Thermocouple Readings Following 2 Point Calibration at 0 and 60 °C
0.001
0
-0.001
-0.002
-0.003
-0.004
-0.005
-0.006
Error. °C
0
10
20
30
40
50
60
Bath Temperature, °C
TC1 (°C)
TC2 (°C)
TC3 (°C)
TC4 (°C)
TC5 (°C)
TC6 (°C)
TC7 (°C)
TC9 (°C)
TC10 (°C)
TC11 (°C)
TC12 (°C)
TC13 (°C)
TC14 (°C)
TC15 (°C)
TC16 (°C)

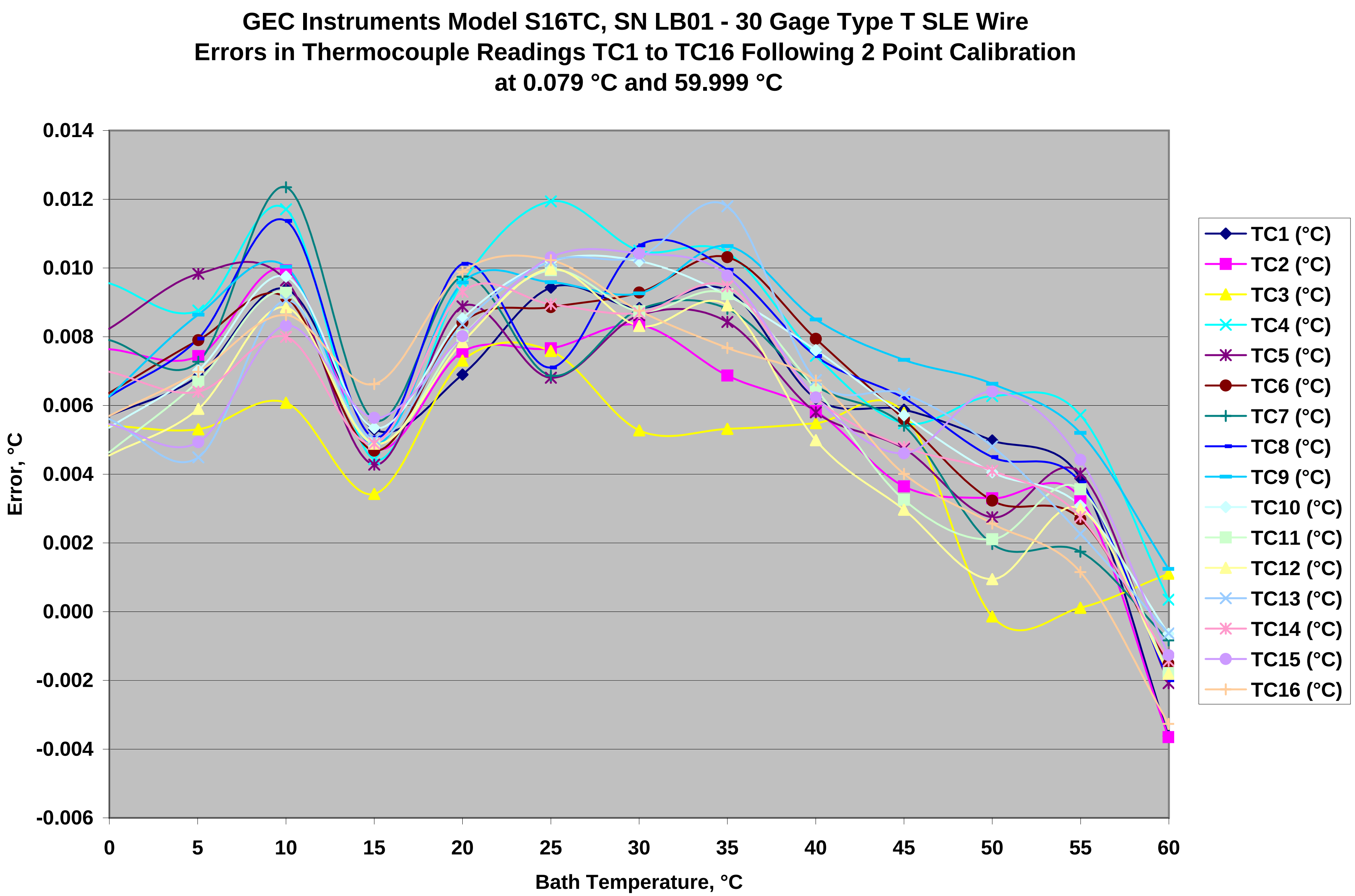

GEC Model S4TC, SN JG01 Thermocouple Instrument, 24 gage Type T SLE Thermocouple Wire, Errors in Thermocouple Readings Following Calibration of Individual Wire from This Lot Then 2 Point Calibration of 4 Thermocouples at -0.003 °C and 59.997 °C
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
Error, °C
0
10
20
30
40
50
60
Bath Temperature, °C
TC1 (°C)
TC2 (°C)
TC3 (°C)
TC4 (°C)


GEC Model S16TC SN GL02 - 36 Gage Type T SLE Thermocouple Wire
Errors in Thermocouple Readings Following 2 Point Calibration at 0.005 °C and 49.993 °C
Error, °C
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
0
5
10
15
20
25
30
35
40
45
50
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)

GEC Instruments Model S16TC, SN KJ01 - 30 Gage Type T Wire - Errors in Thermocouple Readings TC1 to TC10 Following 2 Point Calibration at -0.011 °C and 40.003 °C




GEC Instruments Model S16TC, SN KJ02 - 30 Gage Type T Wire - Errors in Thermocouple Readings TC1 to TC10 Following 2 Point Calibration at -0.011 °C and 40.003 °C
Error, °C
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
0
5
10
15
20
25
30
35
40
Bath Temperature, °C
TC1
TC2
TC3
TC4
TC5
TC6
TC7
TC8
TC9
TC10


GEC Instruments Model S16TC, SN LB01 - 30 Gage Type T SLE Wire
Errors in Thermocouple Readings TC1 to TC16 Following 2 Point Calibration
at 0.079 °C and 59.999 °C
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
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)
TC5 (°C)
TC6 (°C)
TC7 (°C)
TC8 (°C)
TC9 (°C)
TC10 (°C)
TC11 (°C)
TC12 (°C)
TC13 (°C)
TC14 (°C)
TC15 (°C)
TC16 (°C)