Test of MCC E-TC + Long TC in LN2

LabVIEW Slow Control Meeting
2021-December-22

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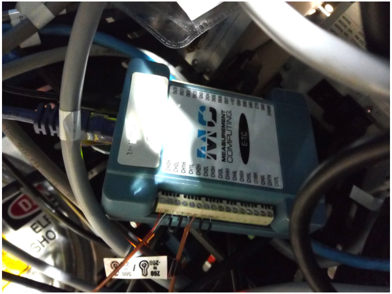
UVA

Test on 2021-12-17

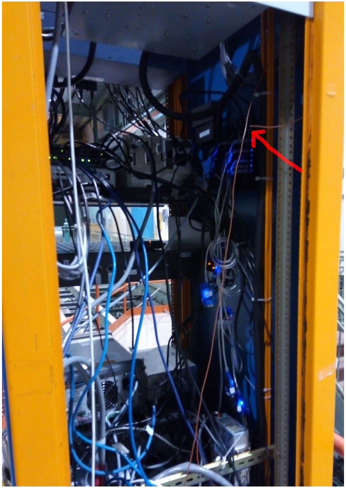
- Aim: Evaluate the accuracy of MCC E-TC with long TC using LN2
  - Absolute temperature scale?
  - Temperature dependence?
- Setup
  - MCC E-TC @ slow-control rack
  - Channel 0 = Long (60-ft) TC
    - Soaked in LN2 on NM3 ground
  - Channel 1 = Short loop
    - For reference
  - Channel 2 = Short (7-ft) TC
    - Hanged at slow-control rack
  - (Channel 3 = Short loop)



- Measurement
  - Recorded at 2 Hz by MCC E-TC
  - For 3.7 days, from 2021-Dec-17 18:00 to 2021-Dec-21 10:30
  - Analyzed the first 1.7 days

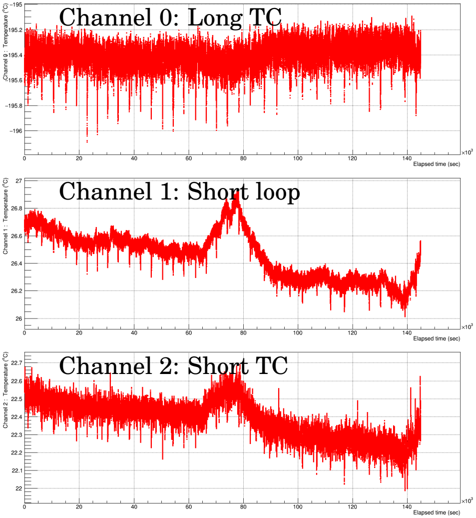
- Long TC in LN2

- Short TC

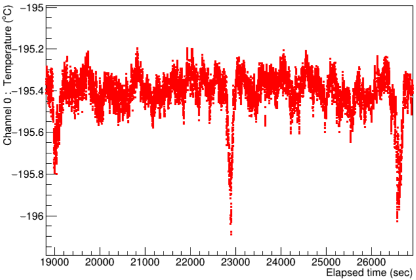


Raw Temperature vs Time

- At 2 Hz for 1.7 days
- Channel 0
  - -195.4 ± 0.2 °C (N2 boiling point @ 14.7 psi $= -195.8$ °C)
  - Hourly dip — *next page*
- Channel 1
  - Air around MCC E-TC
- Channel 2
  - Air at short TC



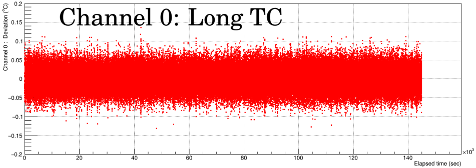
Dip every One Hour

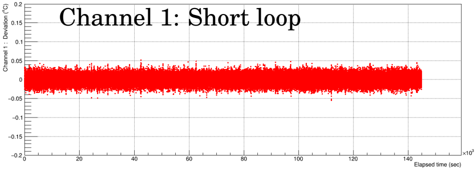


- Not seen in the previous test
- Seen on all channels
  - $\delta^T \sim 0.5\ ^\circ$C on ch. 0 & $0.2\ ^\circ$C on ch. 1-2
    $\Longrightarrow \delta^V \sim 8\ \mu$V, using dV/dT at T of each channel
    $\Longrightarrow \delta^T \sim 6$ K at $T = 4$ K
  - Better be removed
  - Probably due to the vacuum controller (Pfeiffer DCU 600)
- Disappeared after MCC E-TC was moved away on Monday

Short-Term (Single-Point) Deviation

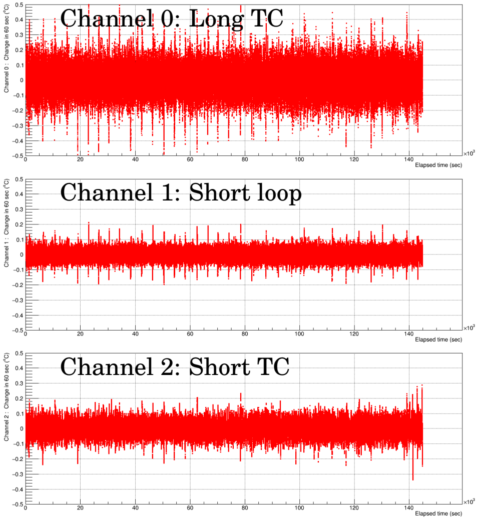
- Deviation from 20-point (= 10 second) average: $\delta_i^T \equiv T_i - \sum_j^{i-10\cdots i-1, i+1\cdots i+10} T_j/20$
- Channel 0
  - Std. dev.: $\sigma^T = 0.0243$ °C — See Appendix
- Channel 1
  - $\sigma^T = 0.00948$ °C
- Channel 2
  - $\sigma^T = 0.00980$ °C
- In common
  - Stable over time
  - Correlated between channels — See Appendix
  - σ^T corresponds to $\sigma^V = 0.4\ \mu$V, using dV/dT at T of each channel
- Expectation at $T = 4$ K
  - $\sigma^T = 0.3$ K





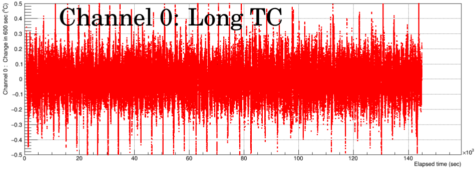
Long-Term Deviation

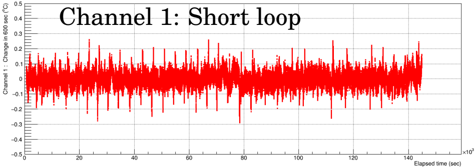
- Change in 60 seconds (i.e. 120 points): $\delta_i^T \equiv T_i - T_{i-120}$
- Channel 0
  - Std. dev.: $\sigma^T = 0.0917\ ^\circ\mathrm{C}$ $\Longrightarrow \sigma^V = 1.5\ \mu\mathrm{V}$
- Channel 1
  - $\sigma^T = 0.0325\ ^\circ\mathrm{C}$ $\Longrightarrow \sigma^V = 1.3\ \mu\mathrm{V}$
- Channel 2
  - $\sigma^T = 0.0470\ ^\circ\mathrm{C}$ $\Longrightarrow \sigma^V = 1.9\ \mu\mathrm{V}$
- In common
  - Stable over time
  - Correlated between channels
- Expectation at $T = 4$ K
  - $\sigma^T = 1.0$-1.4 K

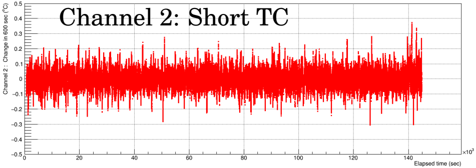


Long-Term Deviation

- Change in 600 seconds (i.e. 1200 points):
  $\delta_i^T \equiv T_i - T_{i-1200}$
- Channel 0
  - Std. dev.: $\sigma^T = 0.114\ ^\circ\mathrm{C}$
    $\Longrightarrow \sigma^V = 1.9\ \mu\mathrm{V}$
- Channel 1
  - $\sigma^T = 0.0469\ ^\circ\mathrm{C}$
    $\Longrightarrow \sigma^V = 1.9\ \mu\mathrm{V}$
- Channel 2
  - $\sigma^T = 0.0561\ ^\circ\mathrm{C}$
    $\Longrightarrow \sigma^V = 2.3\ \mu\mathrm{V}$
- In common
  - Stable over time
  - Correlated between channels
- Expectation at $T = 4$ K
  - $\sigma^T = 1.4\text{-}1.7$ K







Conclusion

- MCC E-TC with long TC
- The major error arises on MCC E-TC itself
  - Correlated between channels
  - Independent of channel inputs (temperature)
- Single-point accuracy
  - $\sigma^T \sim 0.001$ K @ $T = 300$ K
  - $\sigma^T \sim 0.02$ K @ $T = 77$ K
  - $\sigma^T \sim 0.3$ K @ $T = 4$ K
  - In relative, at 2 Hz
- Long-term accuracy
  - $\sigma^T \sim 0.05$ K @ $T = 300$ K
  - $\sigma^T \sim 0.1$ K @ $T = 77$ K
  - $\sigma^T \sim 1$ K @ $T = 4$ K
  - For > 1 minute
- Good enough for magnet-coil temperature under beam
  - $\sigma \sim 0.3$ K for relative change during beam (5 s)
  - Can adjust the absolute scale using the temperature before beam, if necessary

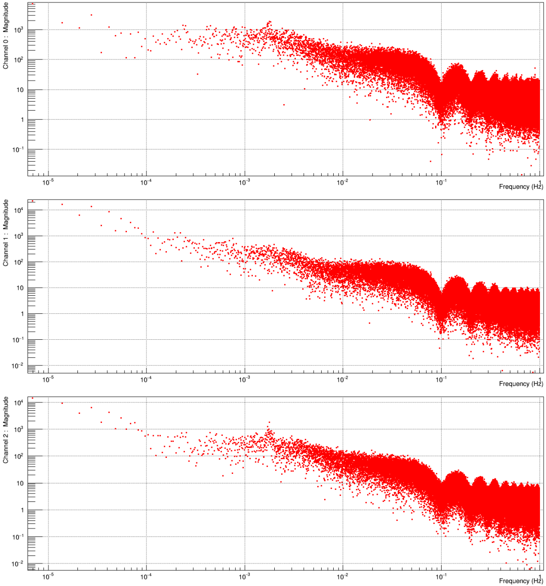
Appendix

Key Parameters of Type-T Thermocouple

- Voltage-Temperature relation
  - `https://jp.flukecal.com/Thermocouple-Temperature-Calculator`
  - `https://jp.flukecal.com/Thermocouple-Table-Voltage-Calculator`

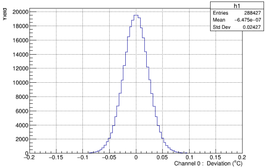
	T (K)	V (mV)	dV/dT (μV/K)
Room	300	$+1.067384$	40.839
Zero	273	-0.005810	38.735
LN2	77	-5.538885	16.296
LHe	4	-6.256512	1.325

FFT of Raw Temperature

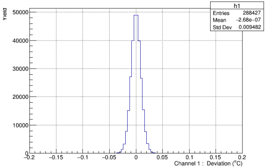


Short-Term Deviation

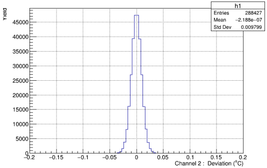
- Channel 0: Long TC



- Channel 1: Short loop

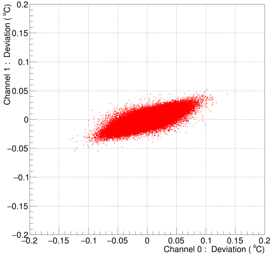


- Channel 2: Short TC

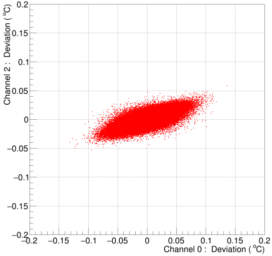


Correlation of Short-Term Deviation

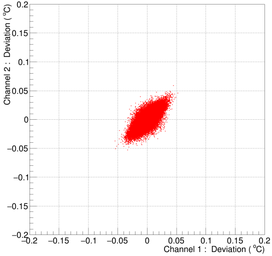
- Ch. 1 vs 0



- Ch. 2 vs 0

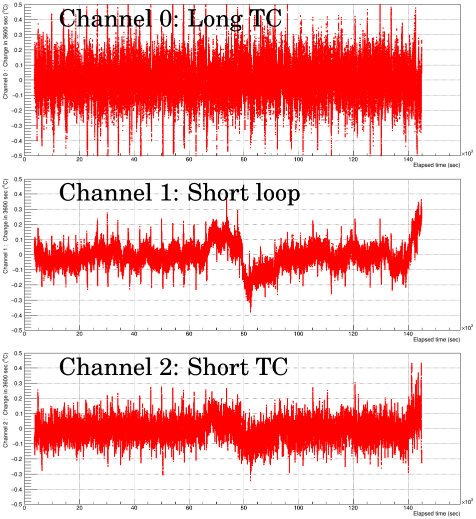


- Ch. 2 vs 1



Long-Term Deviation

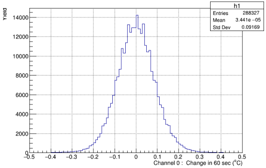
- Change in 3600 seconds (i.e. 7200 points):
  $\delta_i^T \equiv T_i - T_{i-7200}$
- Channel 0
  - Std. dev.: $\sigma^T = 0.119\ ^\circ\mathrm{C}$
    $\Longrightarrow \sigma^V = 1.9\ \mu\mathrm{V}$
- Channel 1
  - $\sigma^T = 0.0780\ ^\circ\mathrm{C}$
    $\Longrightarrow \sigma^V = 3.2\ \mu\mathrm{V}$
  - The effect of real temperature changes is sizable
- Channel 2
  - $\sigma^T = 0.0699\ ^\circ\mathrm{C}$
    $\Longrightarrow \sigma^V = 2.9\ \mu\mathrm{V}$
  - The effect of real temperature changes is sizable
- In common
  - Stable over time
  - Correlated between channels



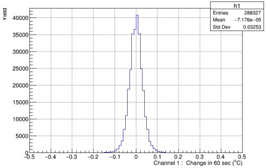
Long-Term Deviation

- Change in 60 seconds

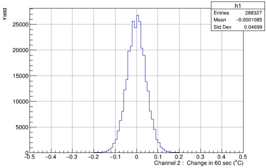
- Channel 0: Long TC



- Channel 1: Short loop



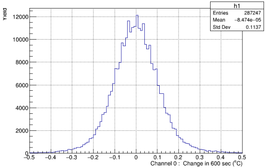
- Channel 2: Short TC

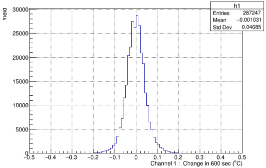


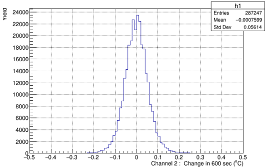
Long-Term Deviation

- Change in 600 seconds

- Channel 0: Long TC
- Channel 1: Short loop
- Channel 2: Short TC



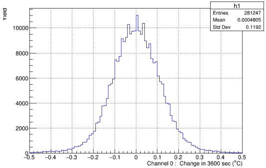




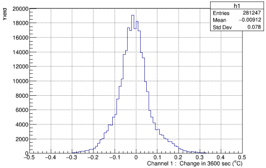
Long-Term Deviation

- Change in 3600 seconds

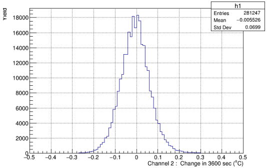
- Channel 0: Long TC



- Channel 1: Short loop



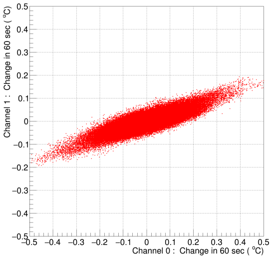
- Channel 2: Short TC



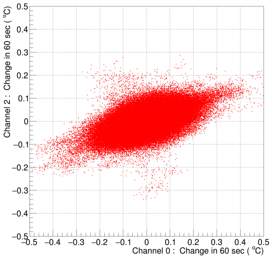
Correlation of Long-Term Deviation

- Change in 60 seconds

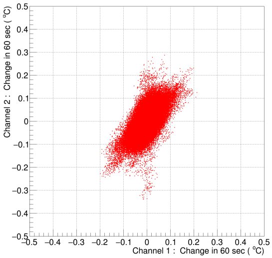
- Ch. 1 vs 0



- Ch. 2 vs 0



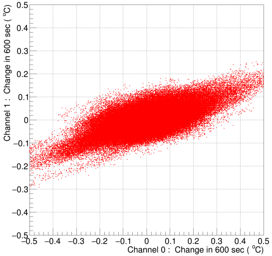
- Ch. 2 vs 1



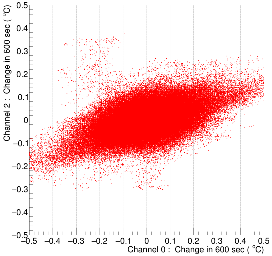
Correlation of Long-Term Deviation

- Change in 600 seconds

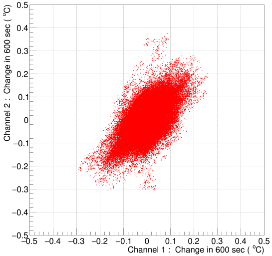
- Ch. 1 vs 0



- Ch. 2 vs 0



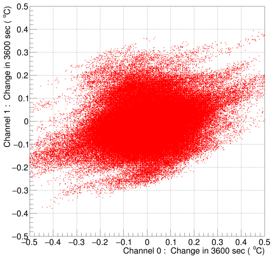
- Ch. 2 vs 1



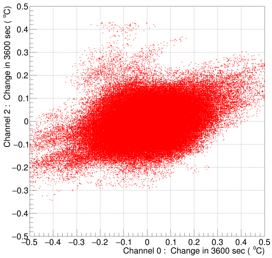
Correlation of Long-Term Deviation

- Change in 3600 seconds

- Ch. 1 vs 0



- Ch. 2 vs 0



- Ch. 2 vs 1