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Thermal Conductance Measurement and Flexibility Enhancement of Flexible Thermal Links

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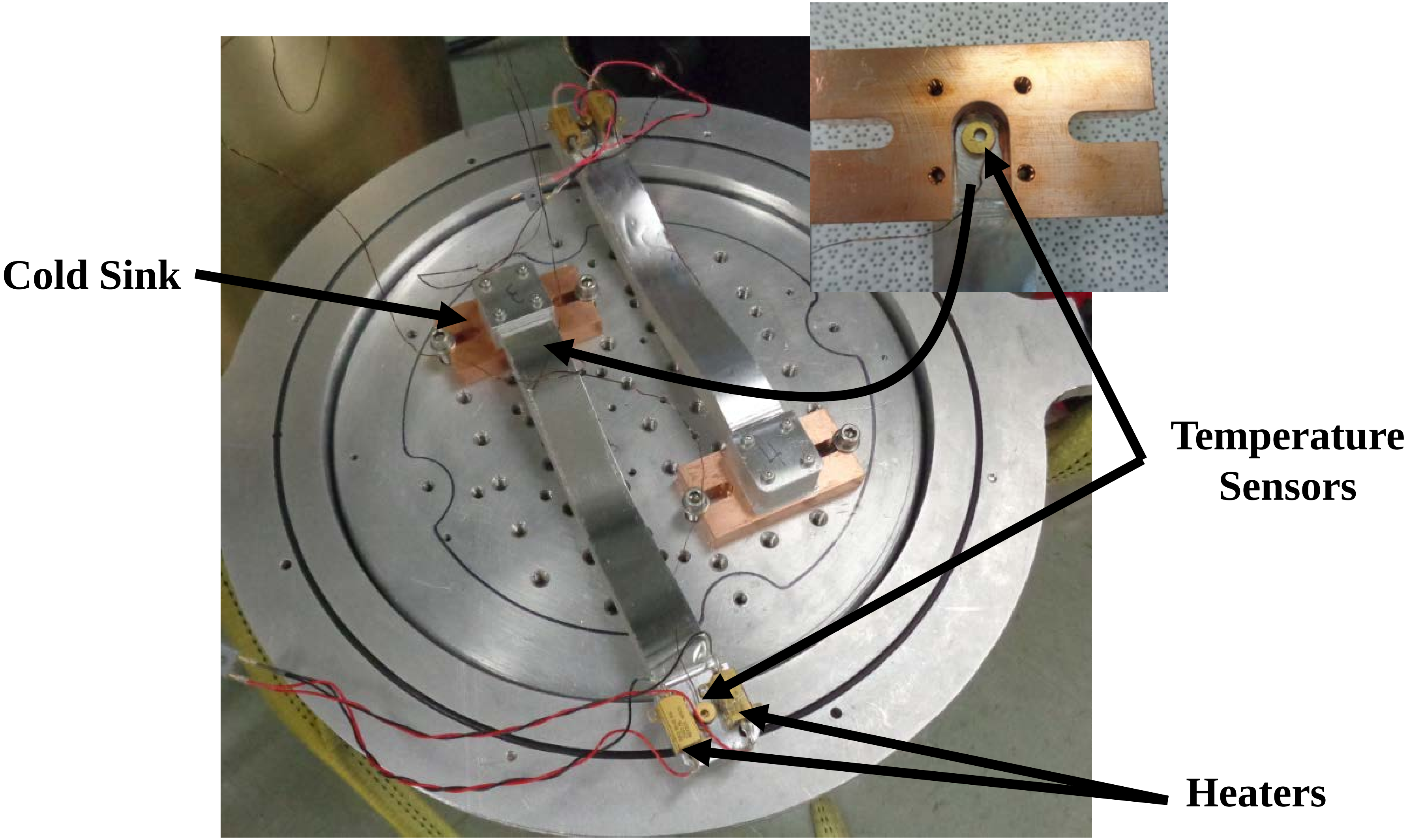
Introduction

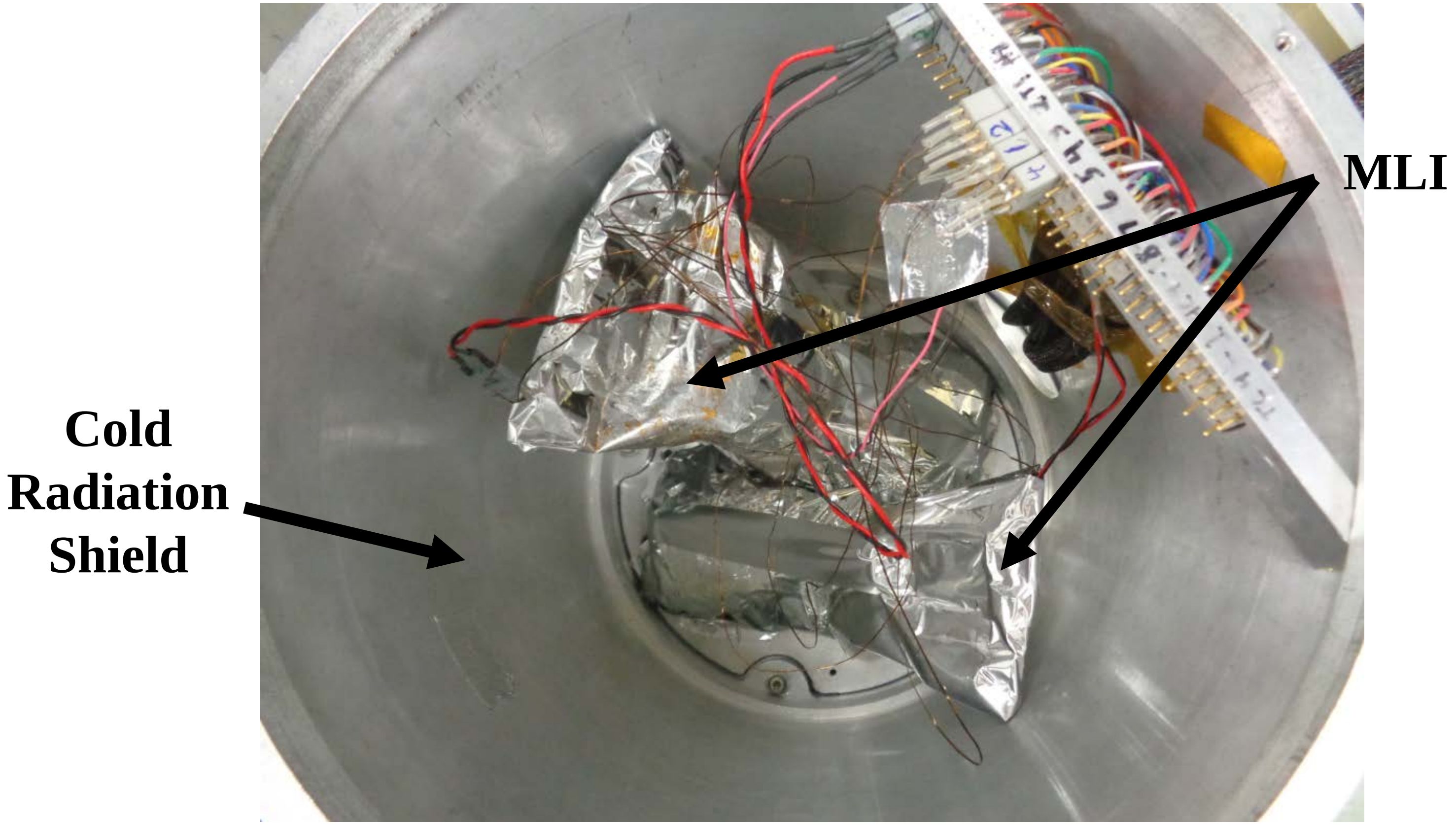
- Flexible thermal links provide a thermally conductive path with low mechanical stiffness
- Scope of this work is to characterize
  - Uncertainty in thermal conductance measurements
  - Compliance improvements gained by slitting foils

Conductance Test Configuration



Installed Into Test Chamber

- Radiation parasitics are minimized by applying MLI to the links and connecting a cold shield to the vacuum chamber cold sink

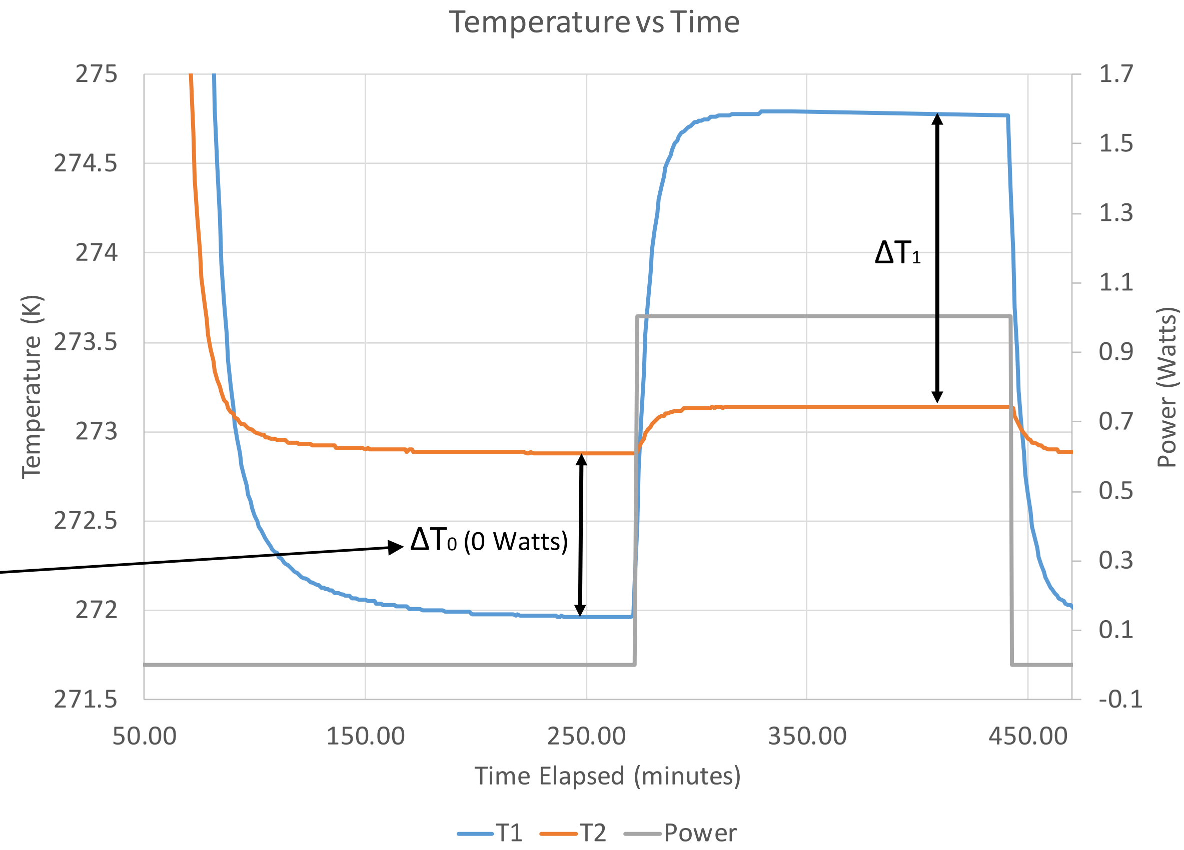


Determining Conductance- Simple

- Stabilize at operating temperature with no heat input
- Stabilize at one power level with heat input

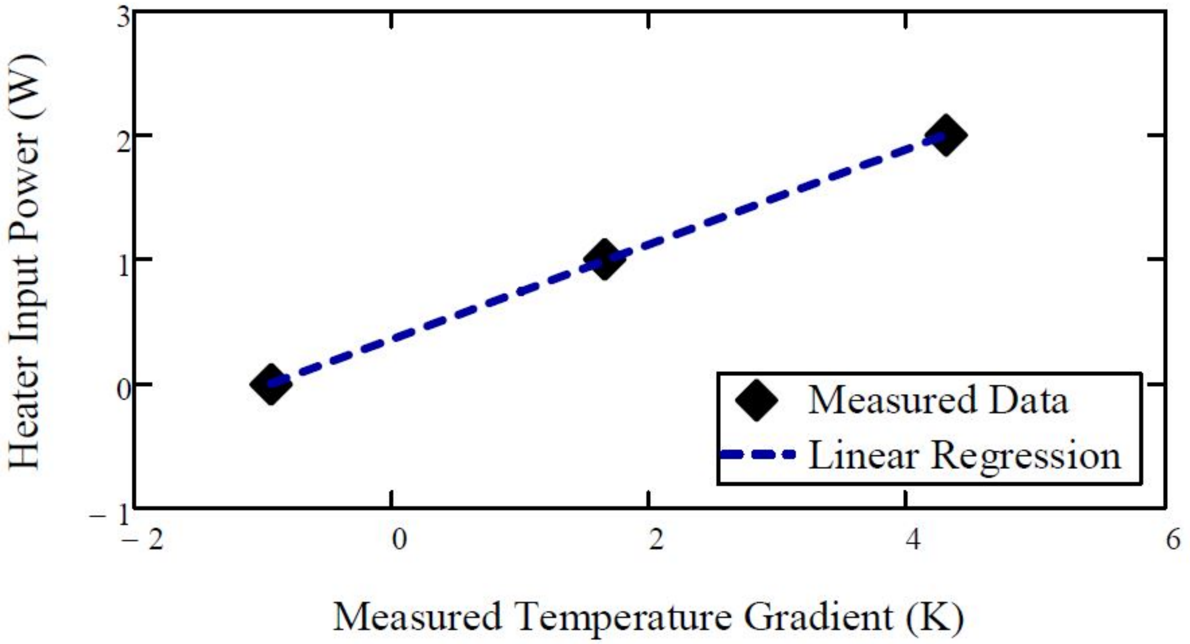
$$G = \frac{Power}{\Delta T_1 - \Delta T_0}$$

ΔT_0 is non-zero due to cal curve / data acquisition differences and small amounts of parasitics



Conductance Determination – Least Squares Fit

- Test at multiple power levels
- Using the data, perform a least squares fit
- The slope of the line is conductance



Conductance Uncertainty Analysis

- The standard error of the slope of the line can be calculated according to

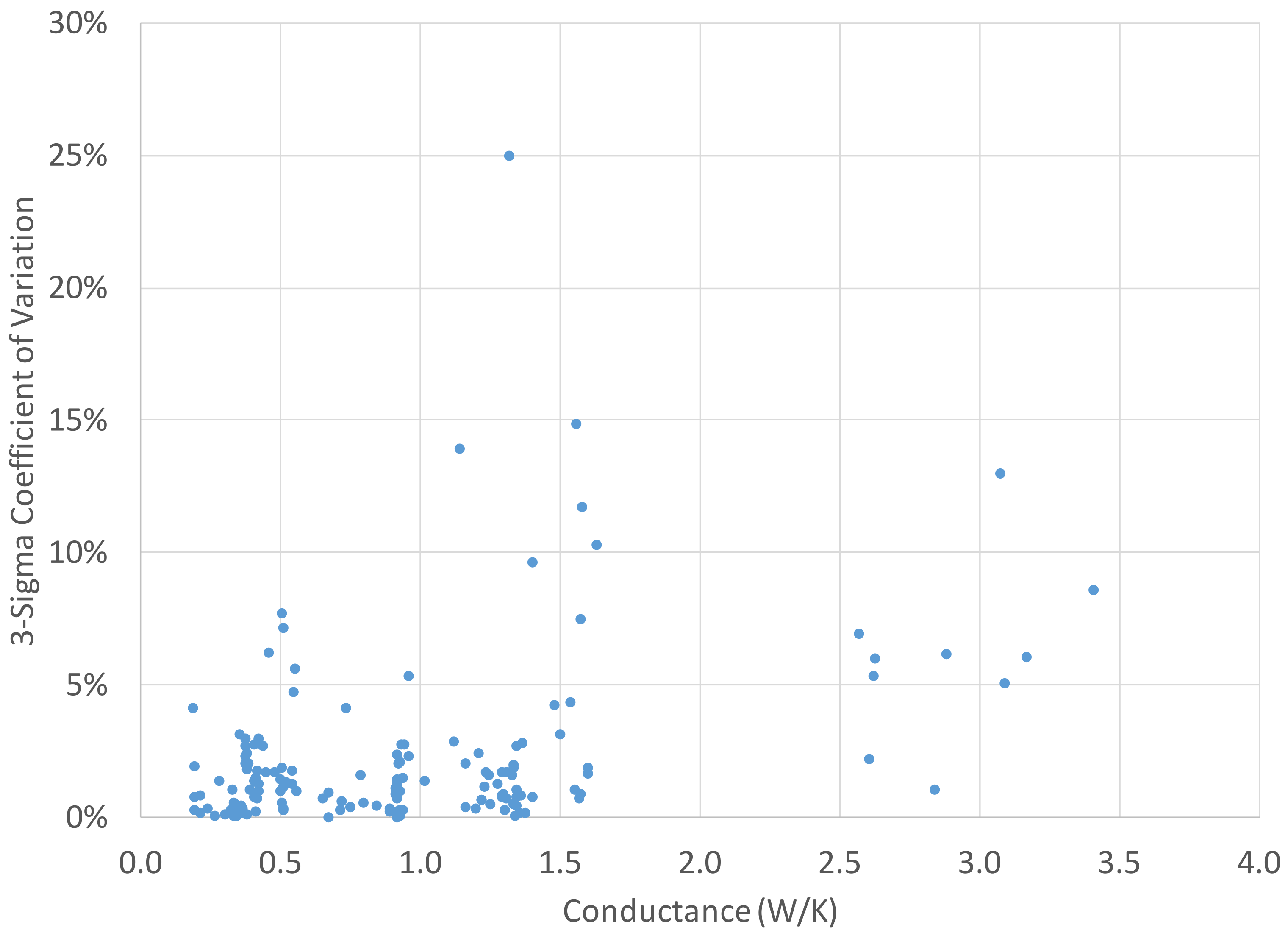
$$s_m = \left(\frac{s_Y^2}{s_{XX}}\right)^{\frac{1}{2}} (eq. 7.21, ref. 1)$$

where

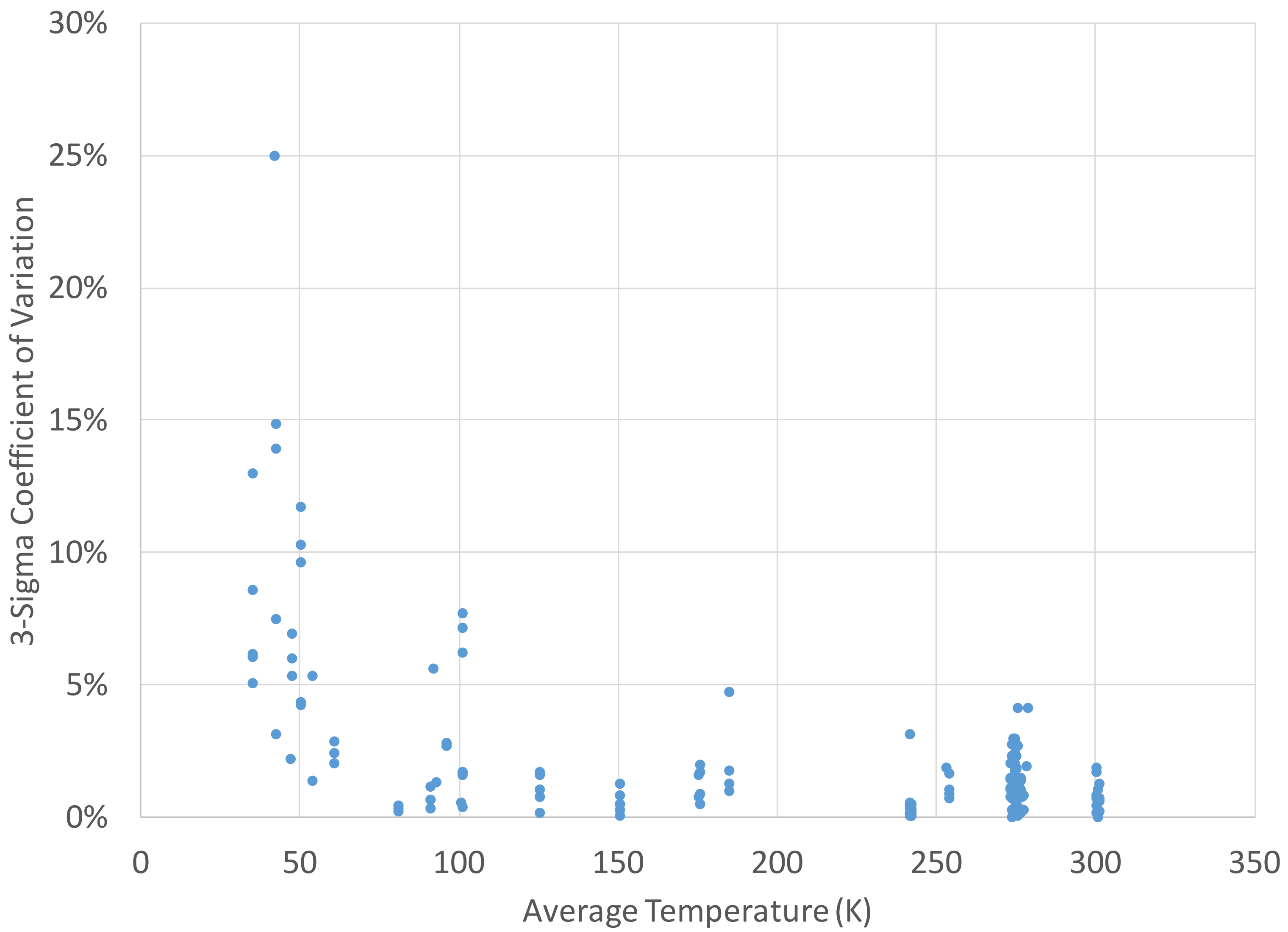
$$s_Y = \left[\frac{\sum_{i=1}^{N}(Y_i - mX_i - c)^2}{N-2}\right]^{1/2} (eq. 7.16, ref. 1)$$

$$s_{XX} = \sum_{i=1}^{N} X_i^2 - \frac{\left(\sum_{i=1}^{N} X_i\right)^2}{N} (eq. 7.19, ref. 1)$$

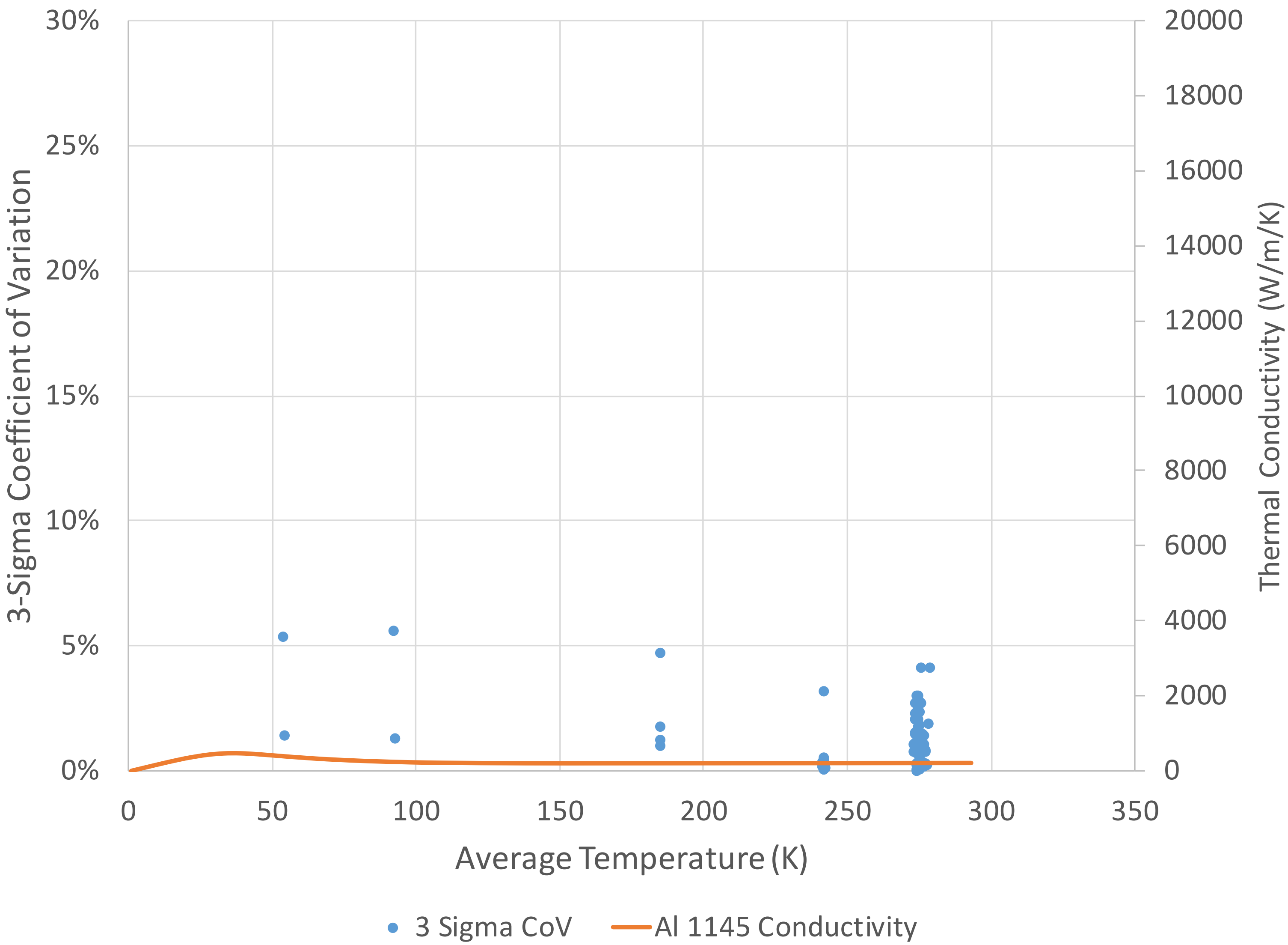
Observed 3-Sigma CoV vs. Conductance



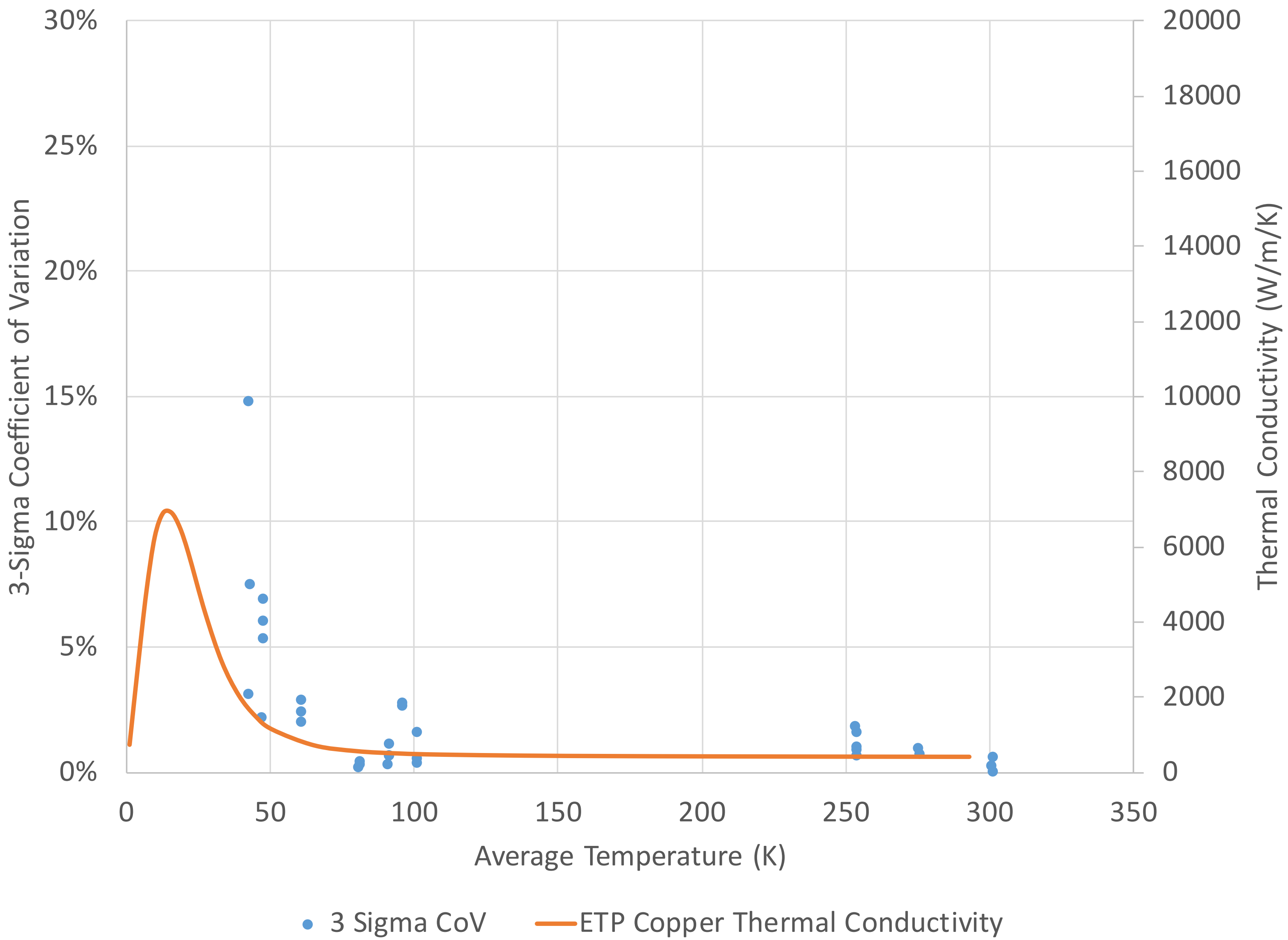
Observed 3-Sigma CoV vs. Temperature



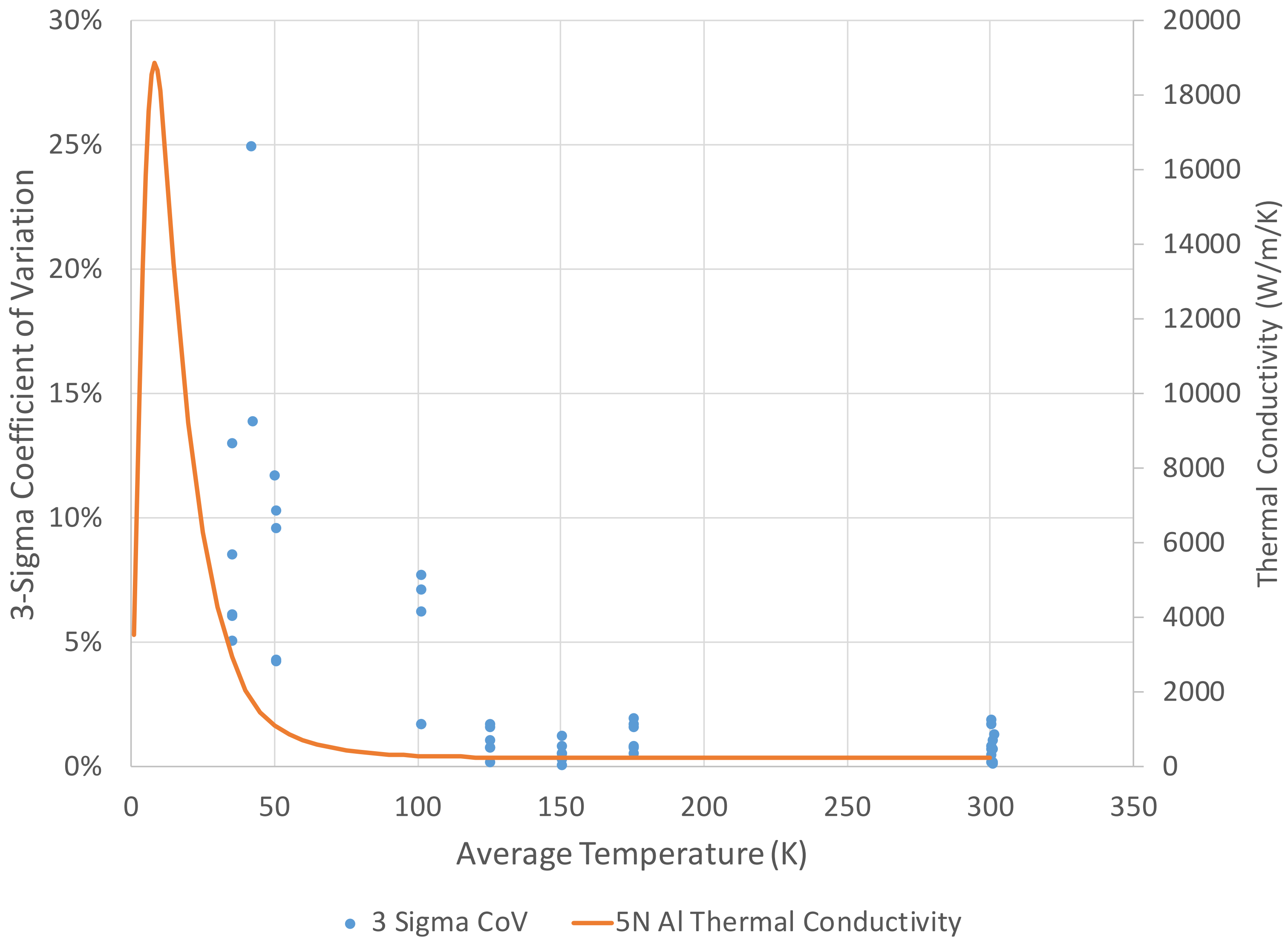
Al 1145 Conductivity and 3-Sigma CoV



Cu Conductivity and 3-Sigma CoV



Al 5N Conductivity and 3-Sigma CoV

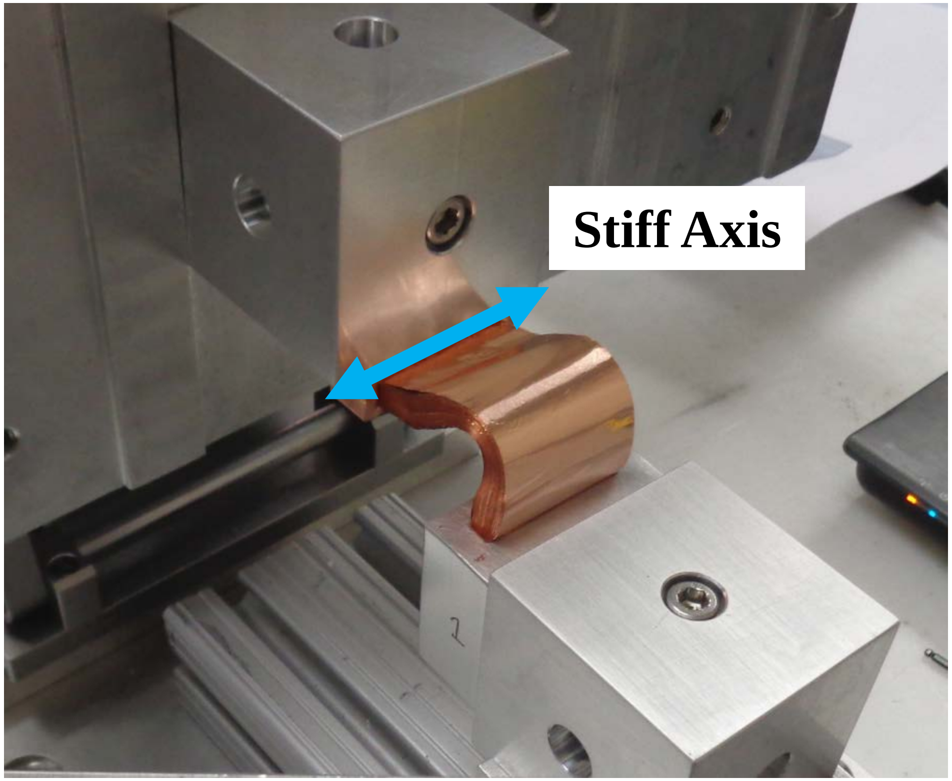


Conductance Testing Summary

- Using a least squares fit enables the calculation of the uncertainty of the slope of the curve that was fit to the test data
- There are additional sources of uncertainty not quantified with this method due to variations in:
  - Sensor location
  - Heater location
  - Interface pressure
- Testing indicates a strong correlation between the slope of the material conductivity curve and the uncertainty of the curve fit

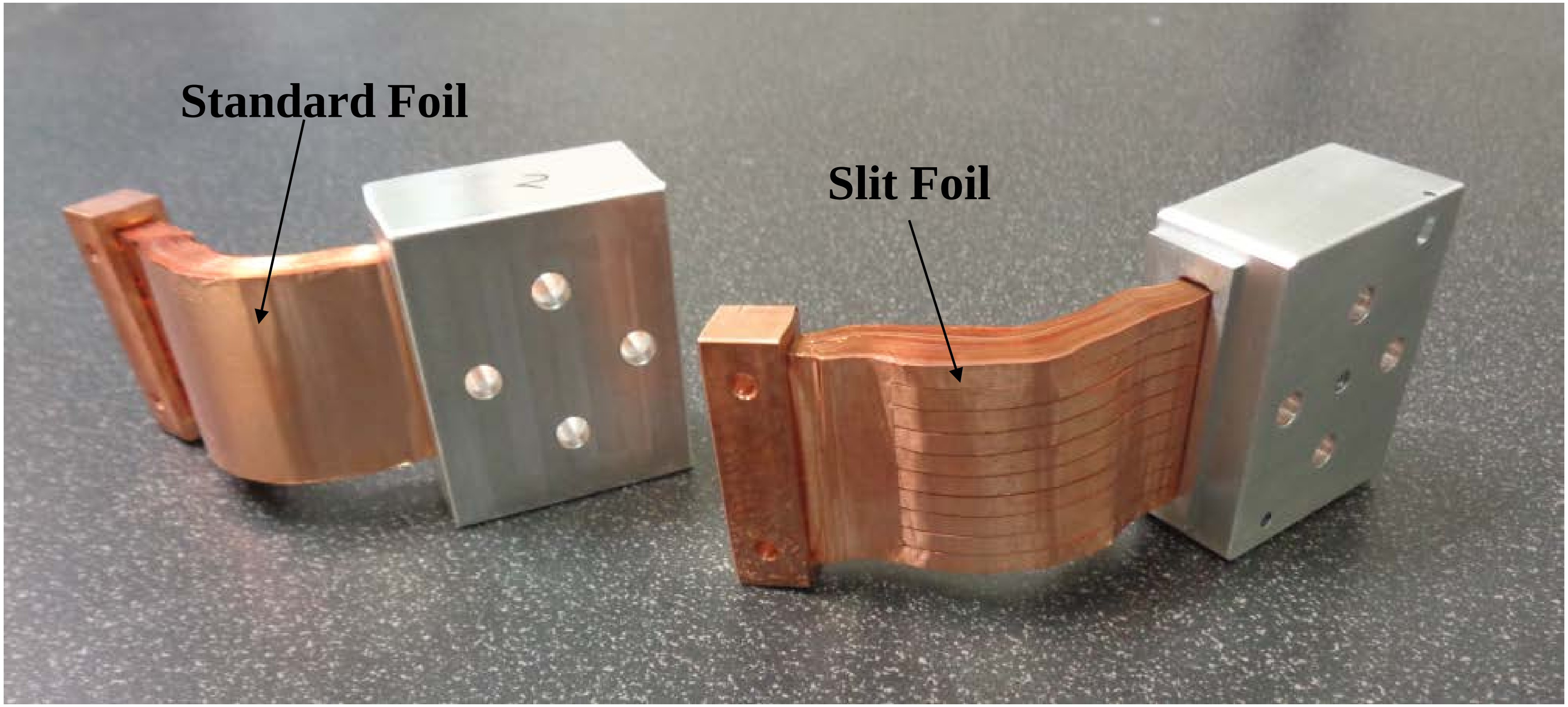
Flexibility Enhancement- Background

- Thermal links made with foils
  - Higher specific conductance than braid links
  - Cleaner than braid links
  - Stiffer than braid links, especially in the plane of the foils



Flexibility Enhancement

- Slitting the foils lengthwise using a chemical etching process reduces stiffness without a significant change in thermal conductance



First Principles Stiffness Change Estimation

- Deflection (z) of a cantilever beam of length l, fixed on one end, with a load of W applied at the opposite end

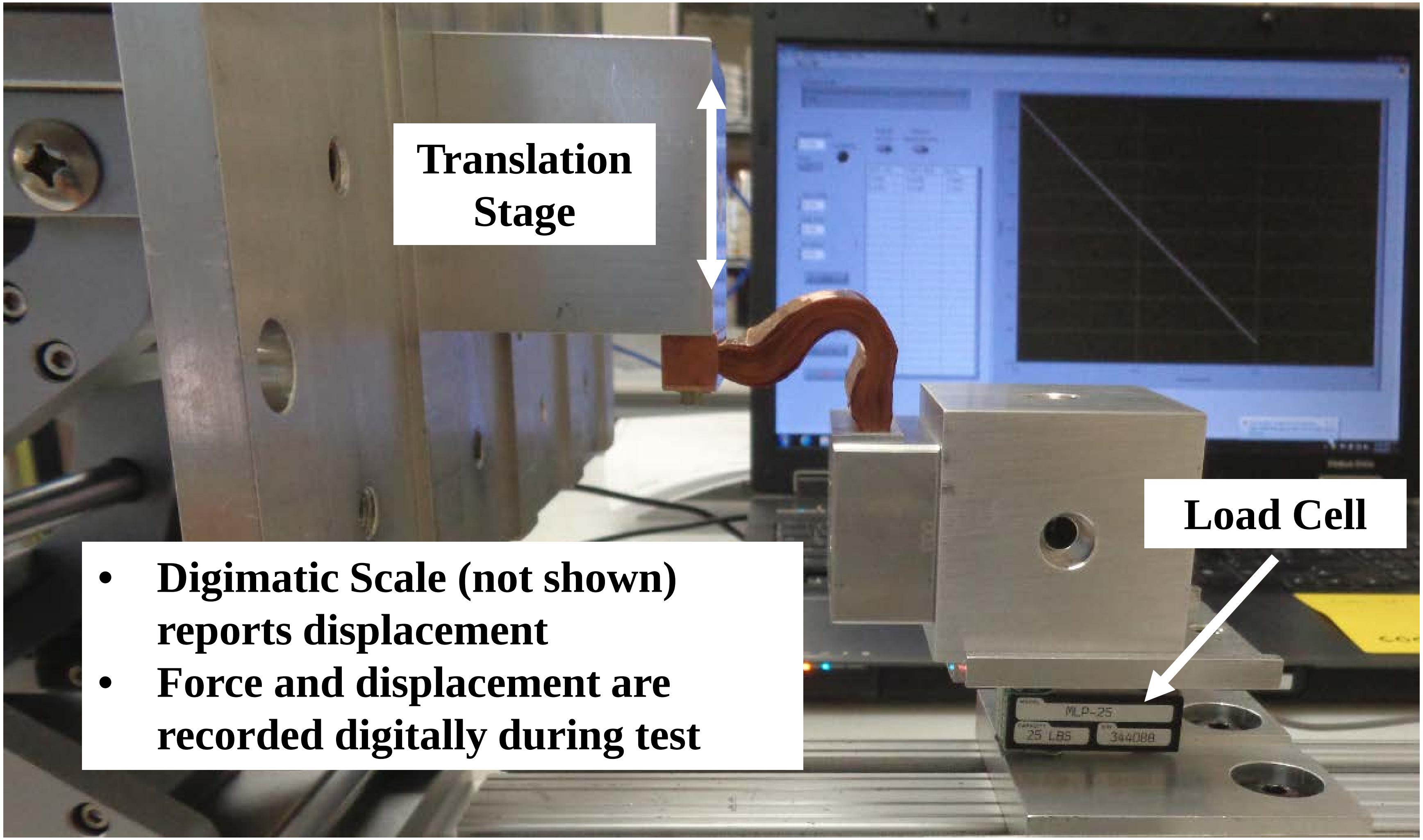
$$z = \frac{-Wl^3}{3EI}$$

- Rearranged to solve for stiffness (k)

$$k = \frac{W}{z} = \frac{-3EI}{l^3}$$

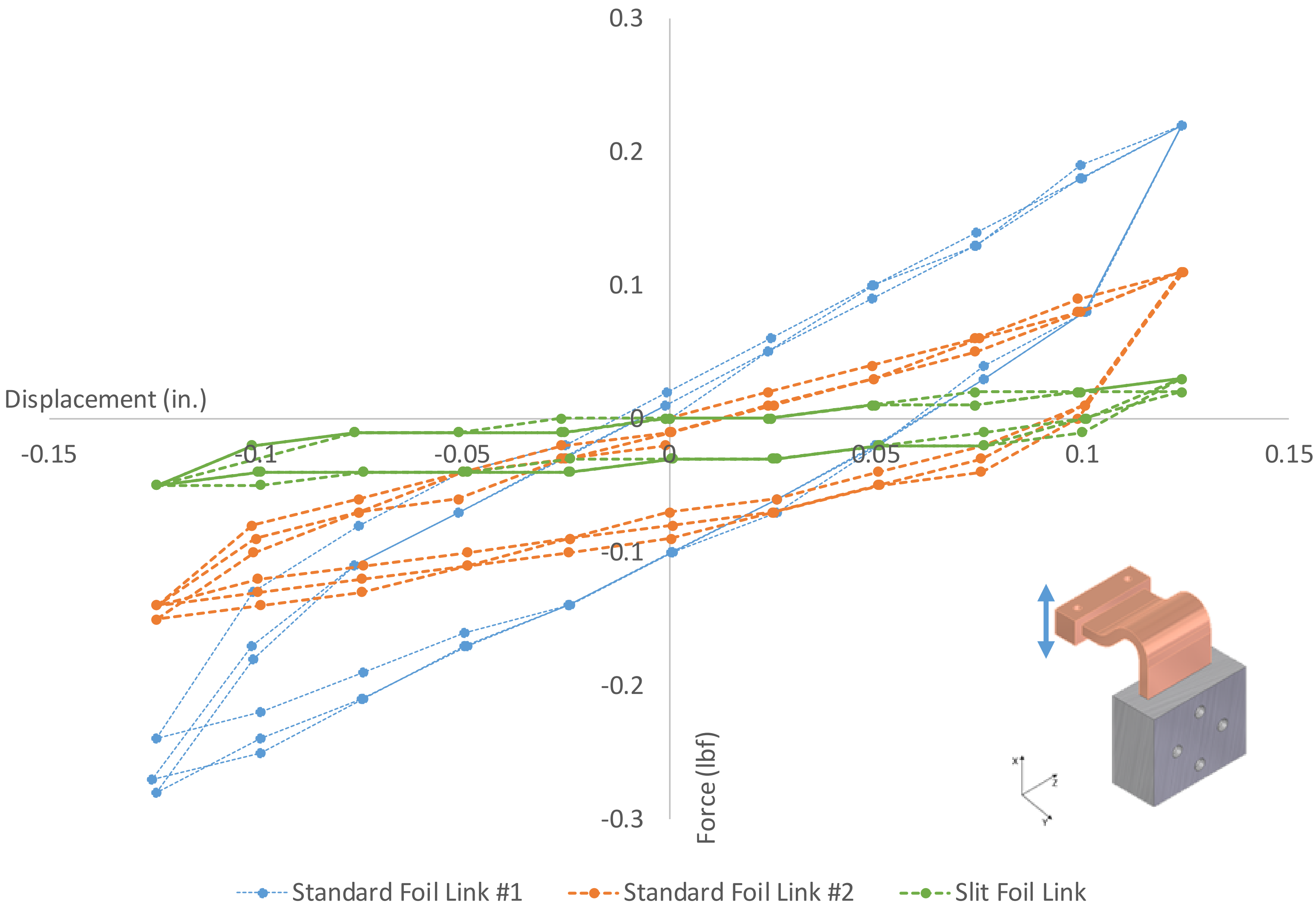
- The only variable changing is I due to slitting the foil into 10 equal sections. The following assumptions were made:
  - Height of the new section is 1/10 the regular foil height
  - The total I for the slit foil link is 10x the value of one section
- These assumptions have the following limitations:
  - Foils are not slit the full length
  - Distance from the neutral axis of each section is not accounted for
- $\frac{k_2}{k_1} = .01$ → expect to see a significant stiffness decrease in this axis

Stiffness Test Configuration

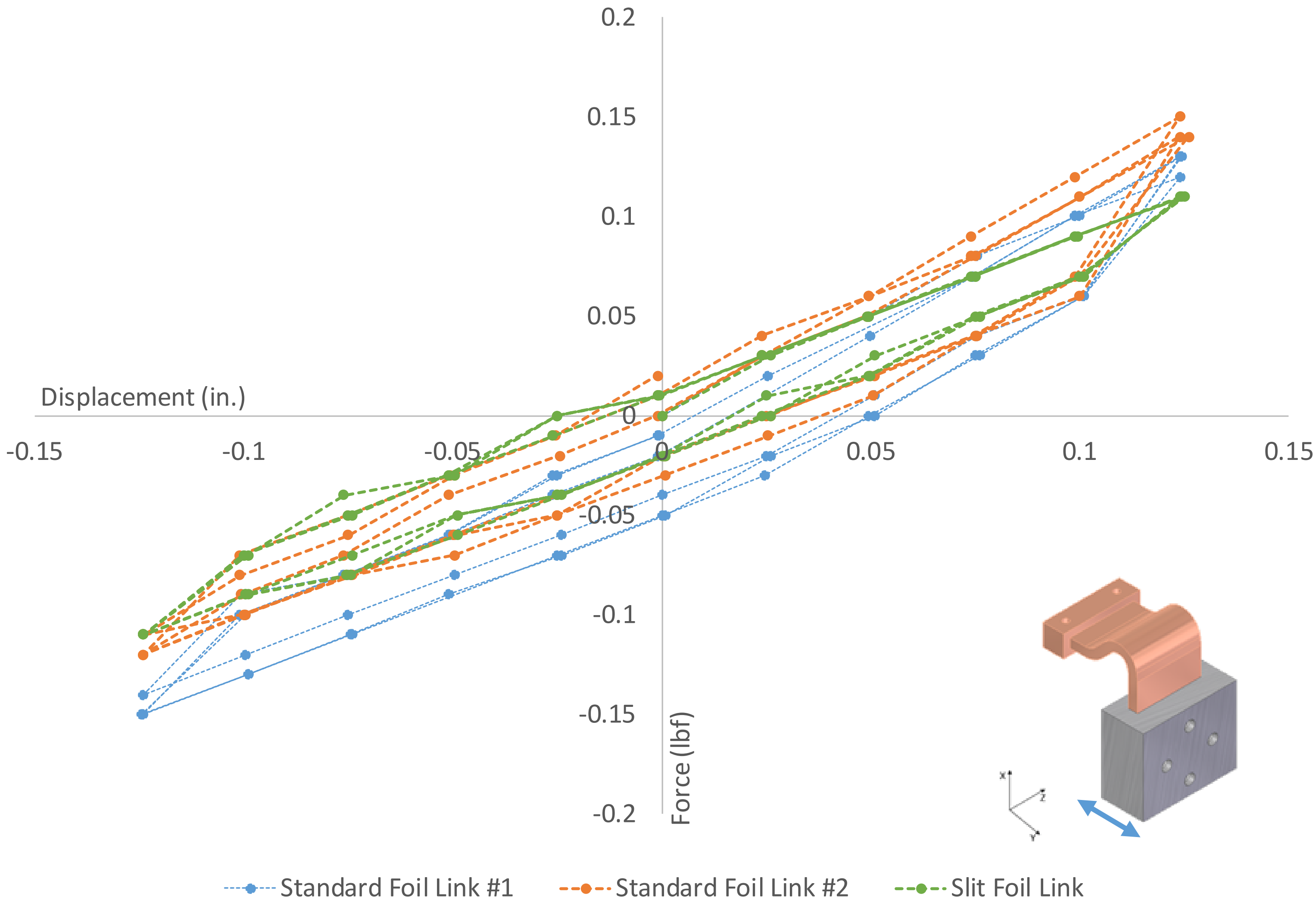


- Digimatic Scale (not shown) reports displacement
- Force and displacement are recorded digitally during test

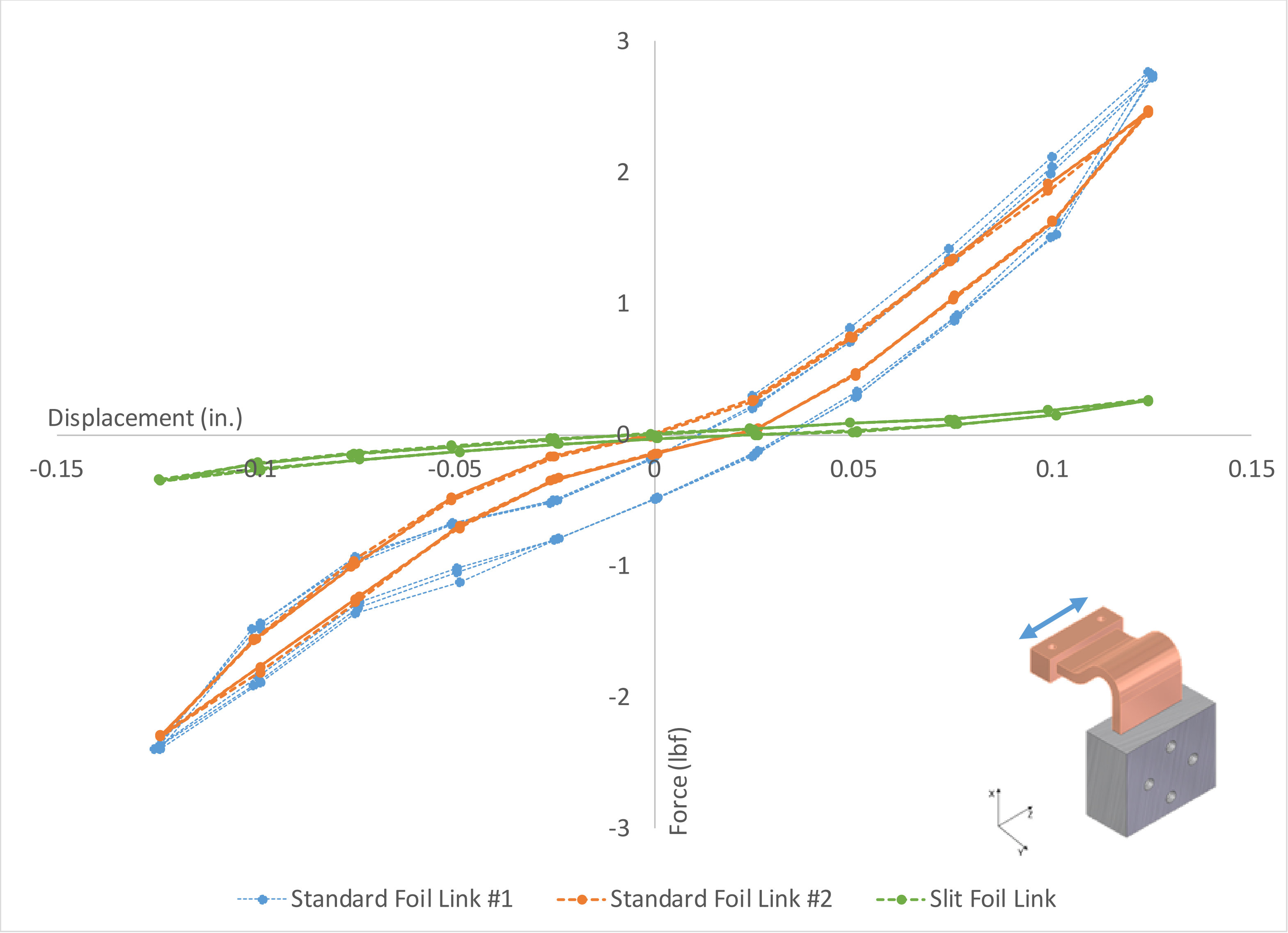
X-Axis Test Results



Y-Axis Test Results



Z-Axis Test Results



Summary / Conclusions

- Stiffness was reduced to 12-14% of original value in the z-axis – expected
- Stiffness was reduced to 18-23% of original value in the x-axis– unexpected benefit
- Slit foils are an effective method for reducing stiffness if program constraints allow
  - ~$1k unit cost increase
  - 4 week lead time addition

References

1. Coleman, H., & Steele, W. (2009). Experimentation, validation, and uncertainty analysis for engineers, 3rd ed. Hoboken, NJ: Wiley.