Reliability Assessment for NanoEngineered Fatigue Crack Sensor

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structural health monitoring
multi-functional materials
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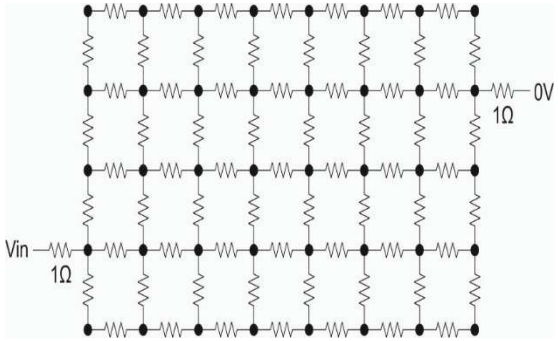
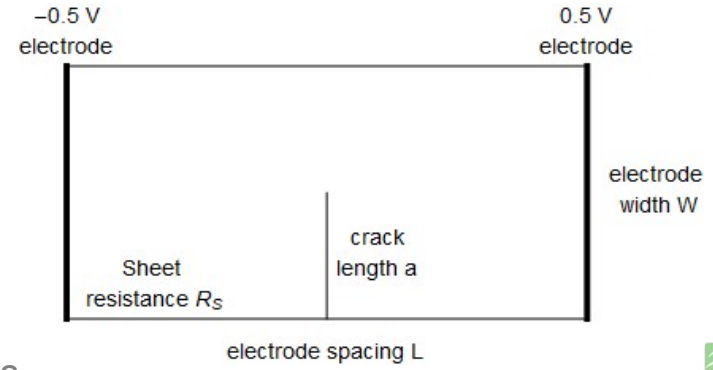
AF14-065 Phase II SBIR – Continuum Crack Gauge

- **Targeted detection of flaw growth in known location**
  - Addressing fleetwide problems or critical locations
  - Alternative to traditional crack gauge
  - Focus on crack growth in metallic parts for fixed-wing aircraft

- **Crack detection mechanism**
  - Carbon Nanotube (CNT) assembly to be bonded to structure skin
  - CNT network electrical resistance changes proportional to crack length
  - Multiple electrode pairs can be used to detect crack orientation
  - Completely passive sensor, crack "recorded" even when no power applied





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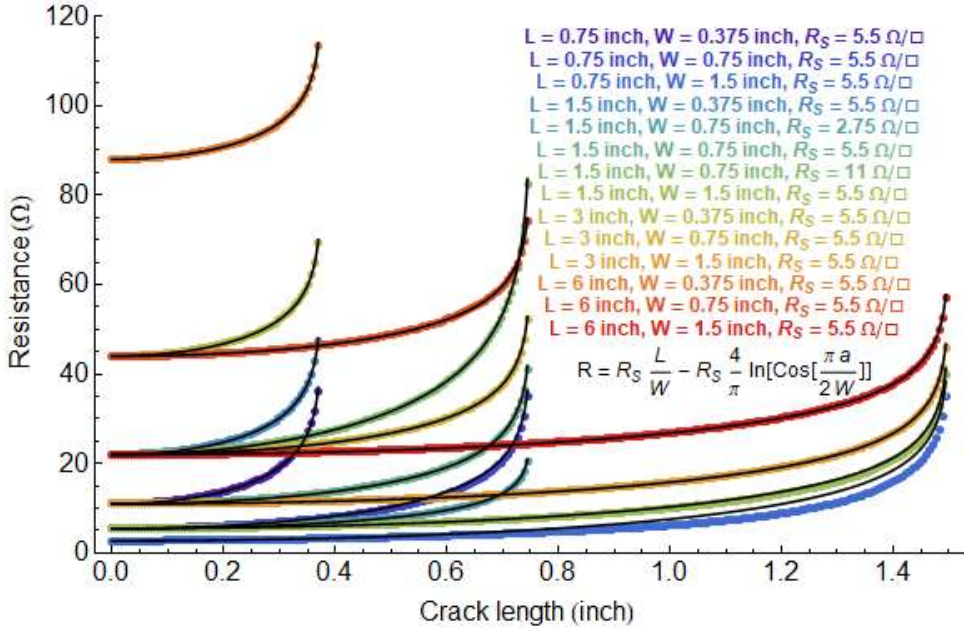
Modeling

- ANSYS 18.1 finite element model of the CNT sensor with a crack
  - Adjust electrode spacing & width, sheet resistance and crack length
  - 4096 eight node plane230 elements with voltage degrees of freedom
- Resistance increases as a function of crack length
- R, were fitted to:

$$R = R_0 - R_S \frac{4}{\pi} \ln\left(\cos\left(\frac{\pi\, a}{2\, W}\right)\right)$$

- R0 is resistance without crack:

$$R_0 = R_S \frac{L}{W}$$



- Equations fits well to results
  - Except for W / L $\geq$ 2 small crack lengths comparted to the width
  - Equation is approximately given by: $R = R_0 + R_S \frac{\pi\, a^2}{2\, w^2}$ $\quad small\ a/w$

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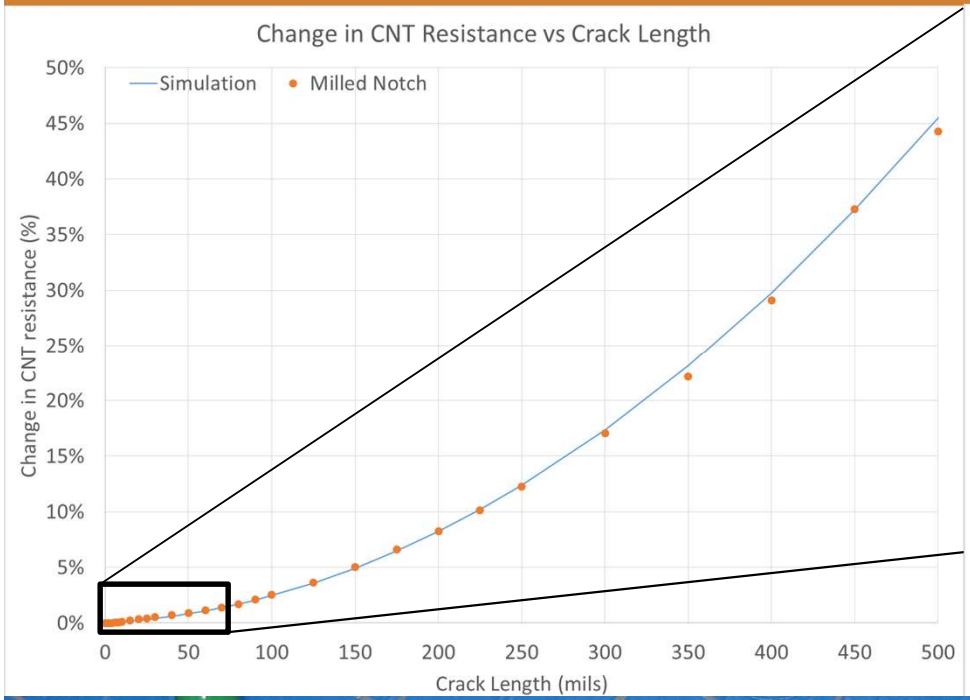
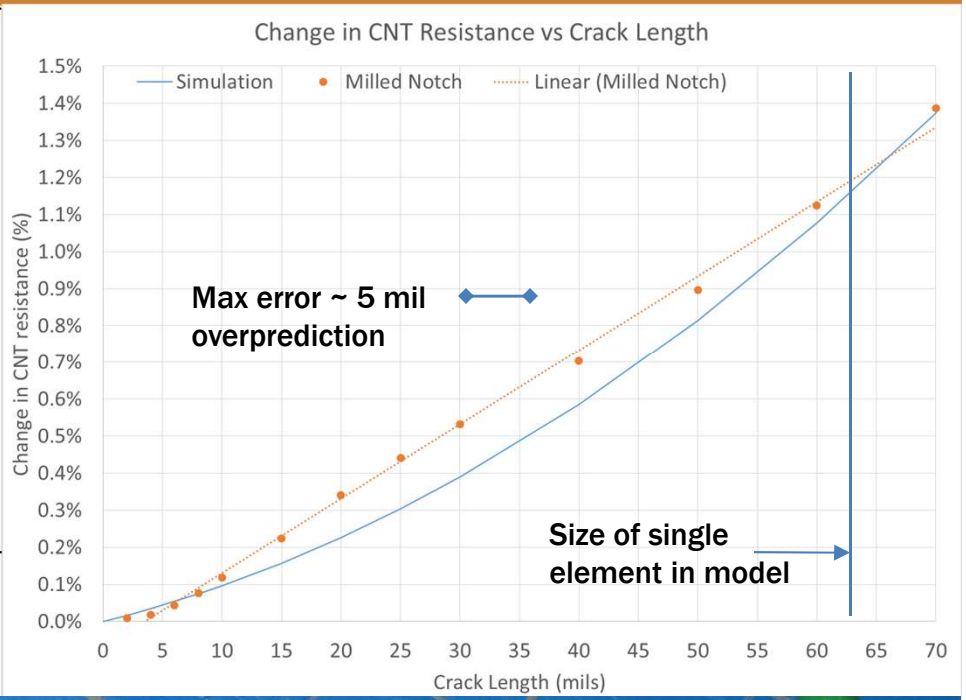
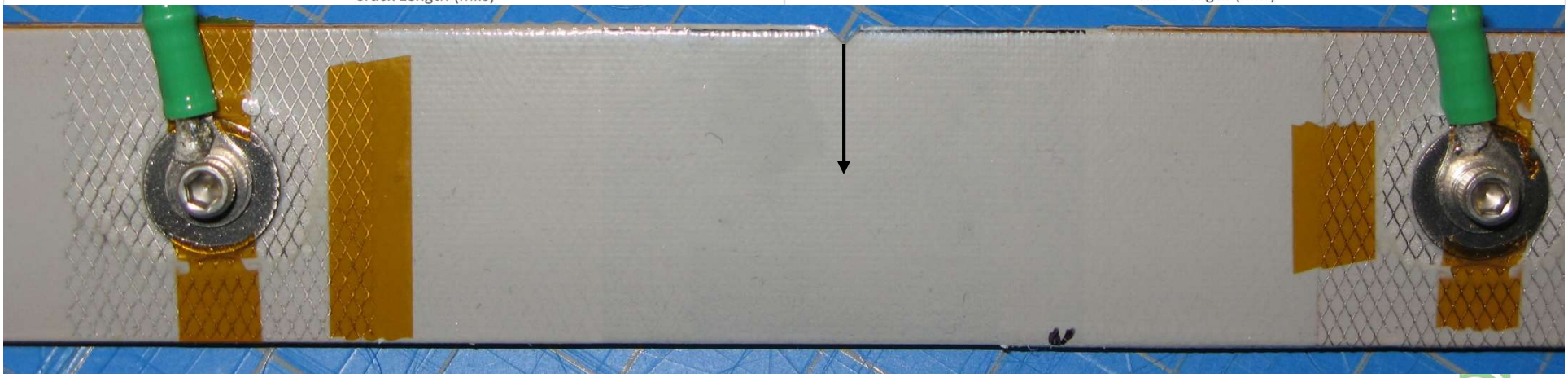
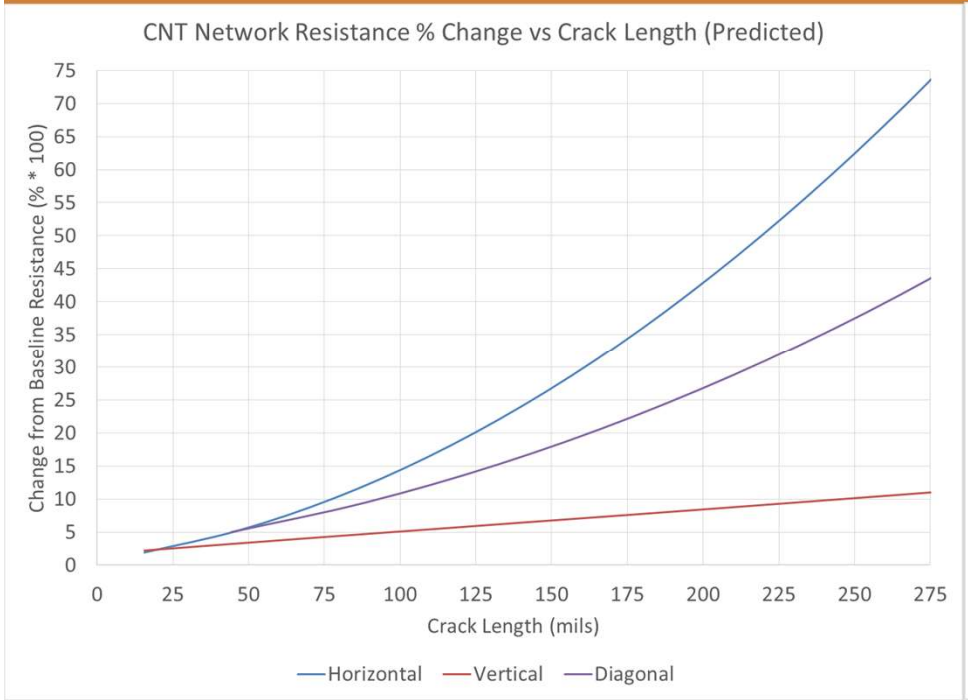
Continuum Crack Gauge Model 1D Validation

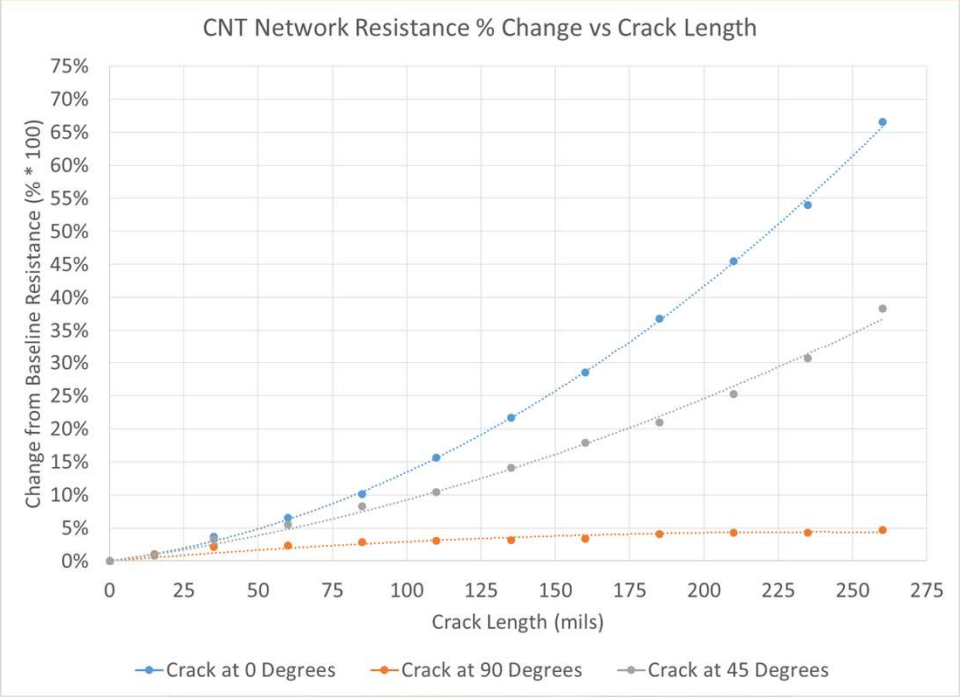


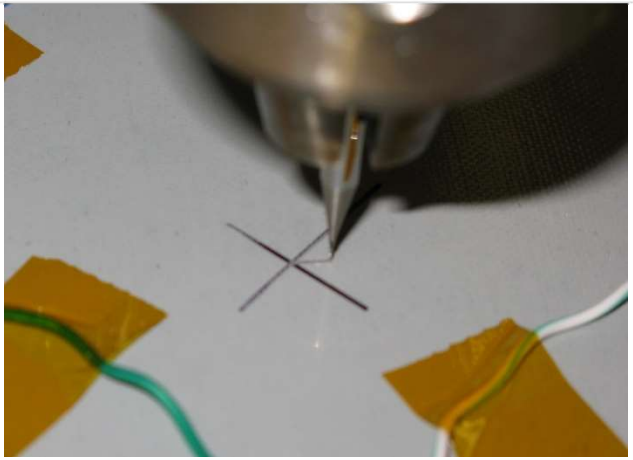




Continuum Crack Gauge Model 2D Validation







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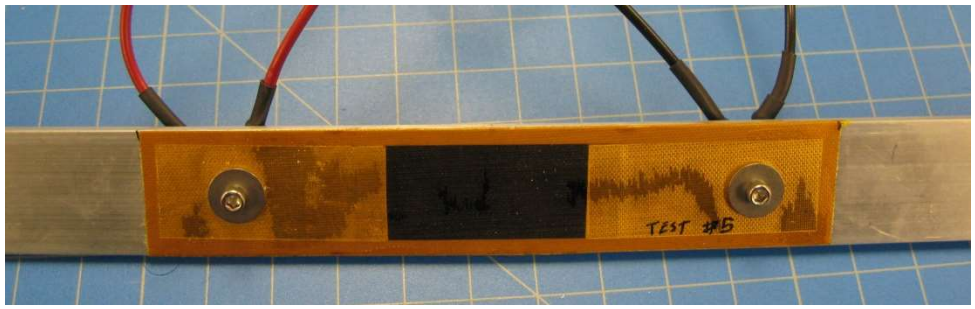
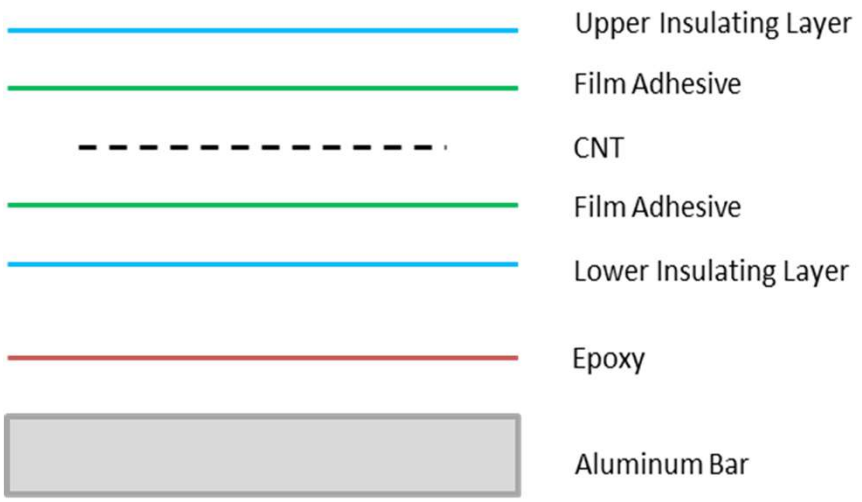
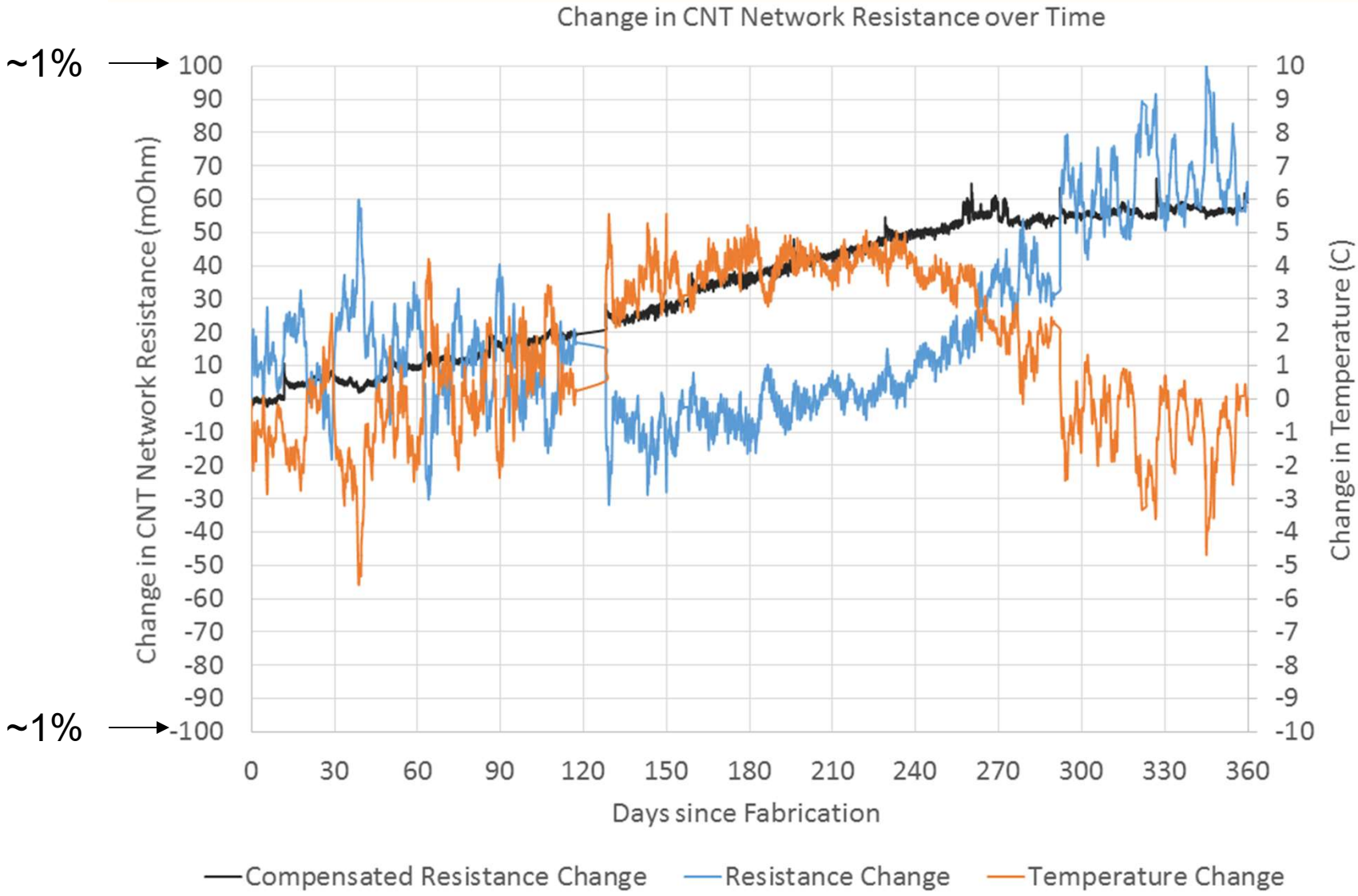
Sensor Design

- Sensor patches are comprised of several stacked layers
  - Upper insulation layer (0.001” thick)
  - Film adhesive (0.001” thick)
  - CNT layer (0.001” thick, “disappears” into adhesive when integrated)
  - Film adhesive (0.001” thick)
  - Lower insulation layer (0.001” thick)
  - Strain gauge epoxy (~0.001” thick)





Measured Resistance Drift over 1 Year



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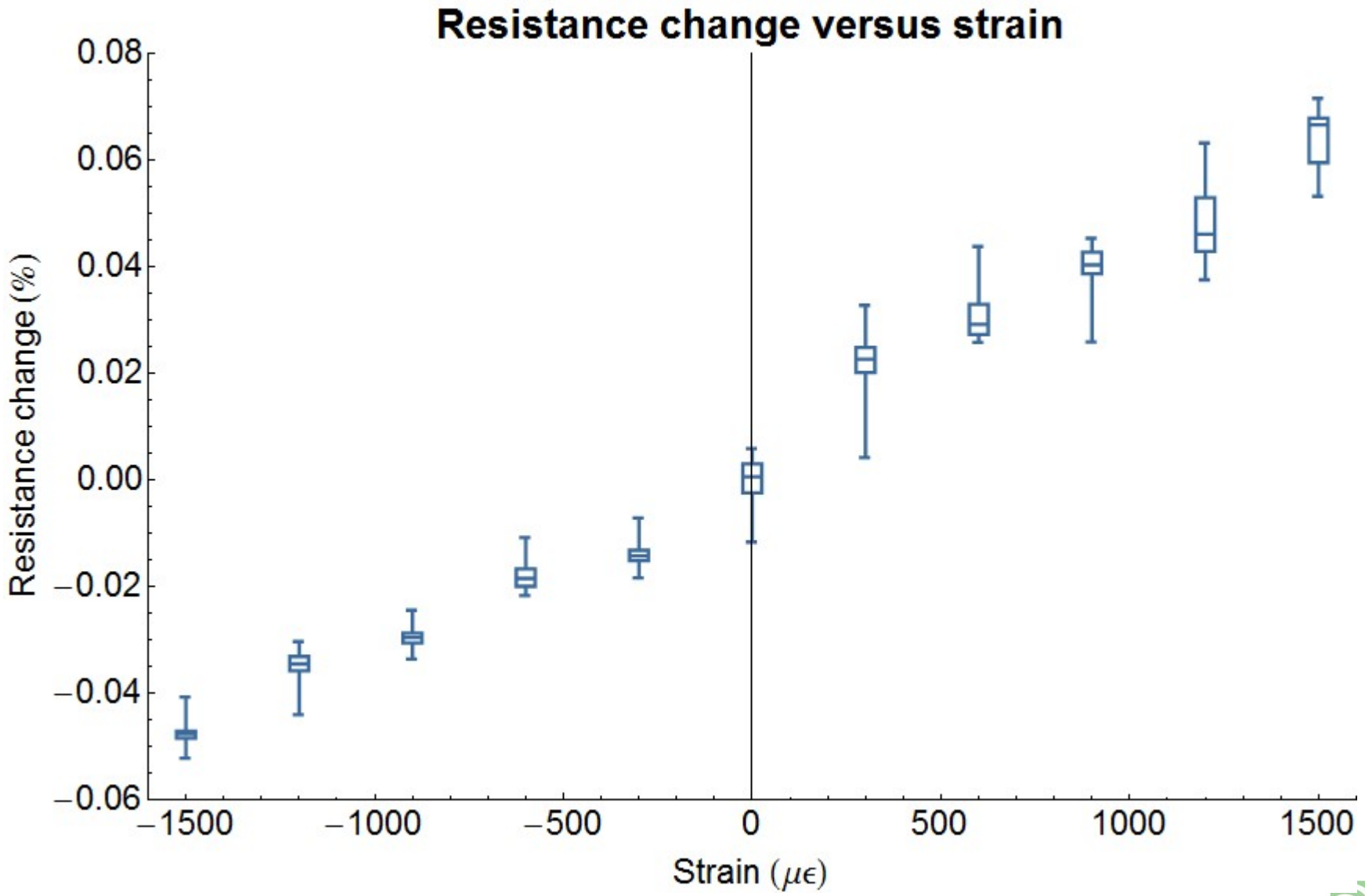
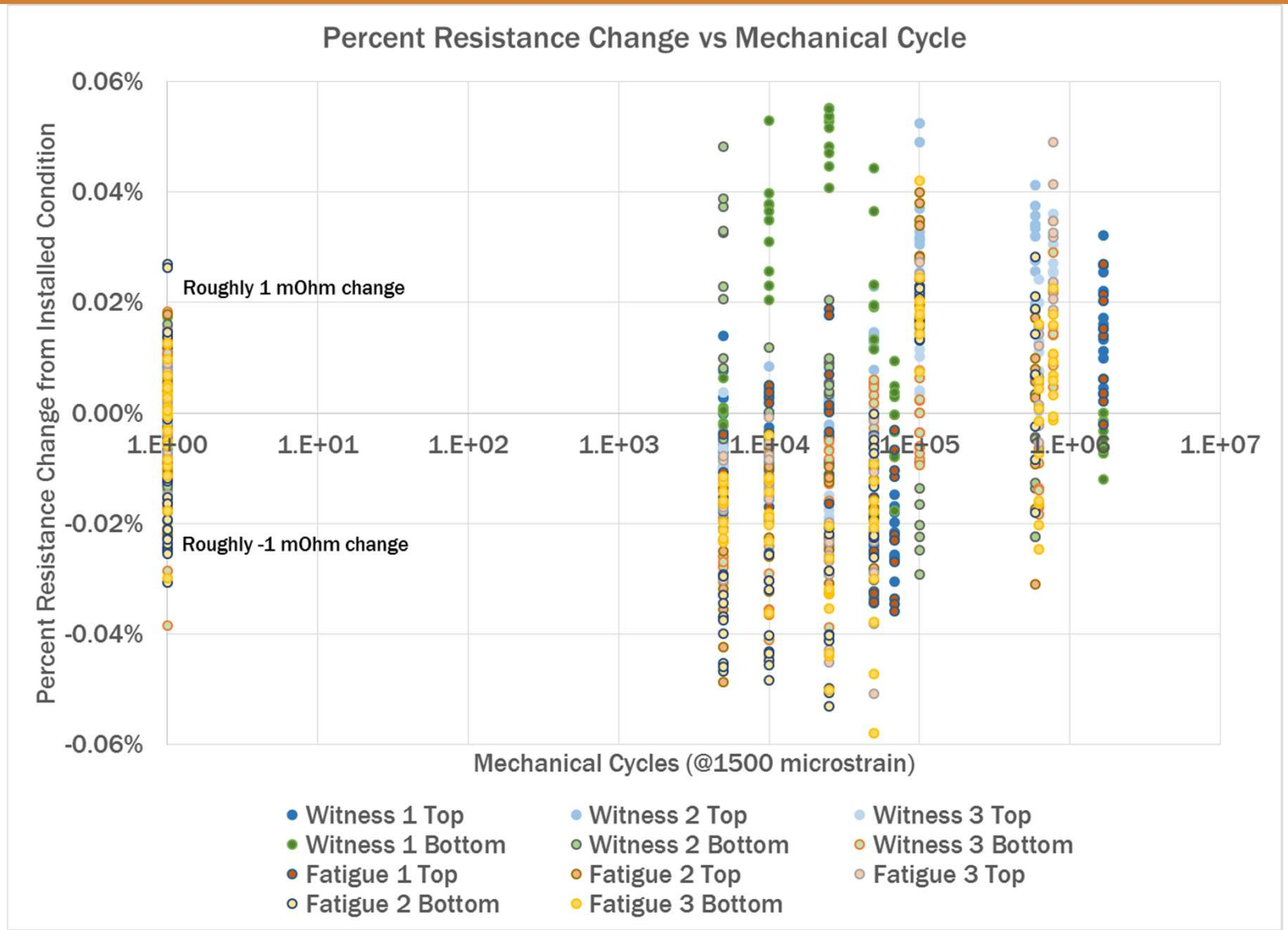
Measured Resistance Under Enforced Strain

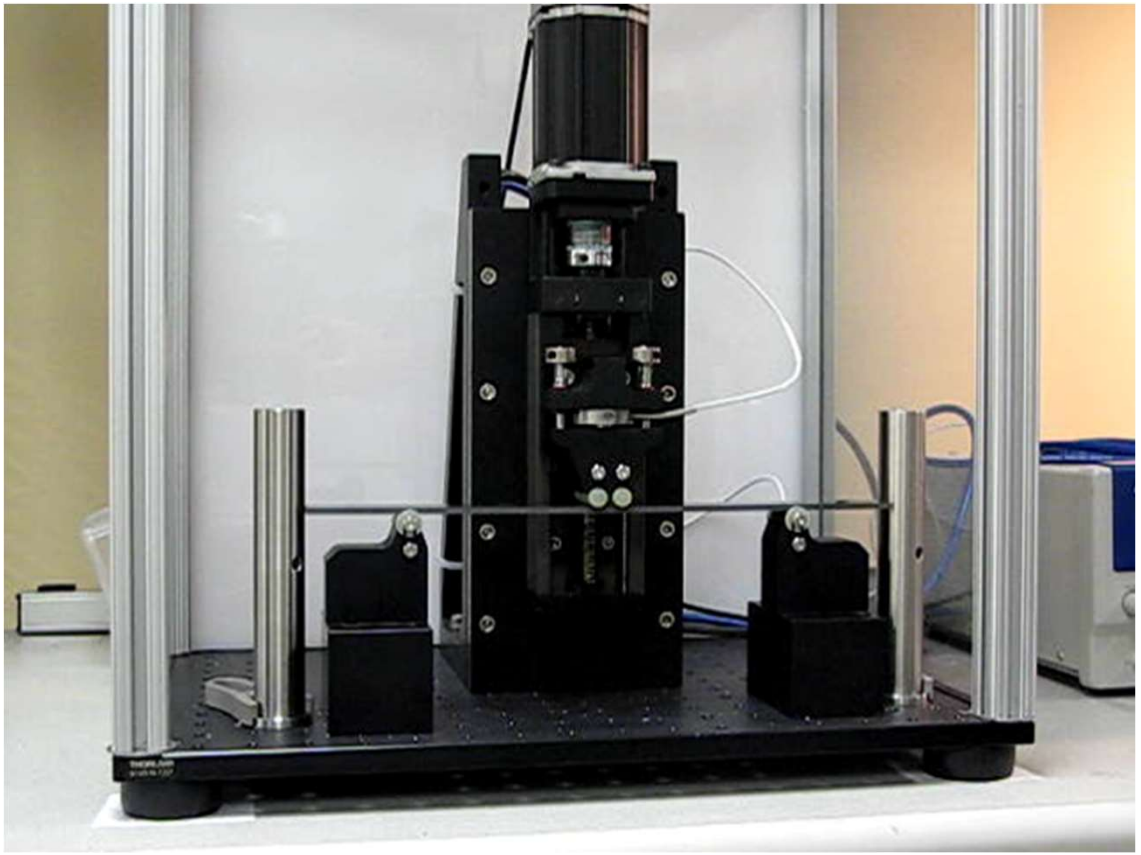


Measured Resistance Under Fatigue Loading

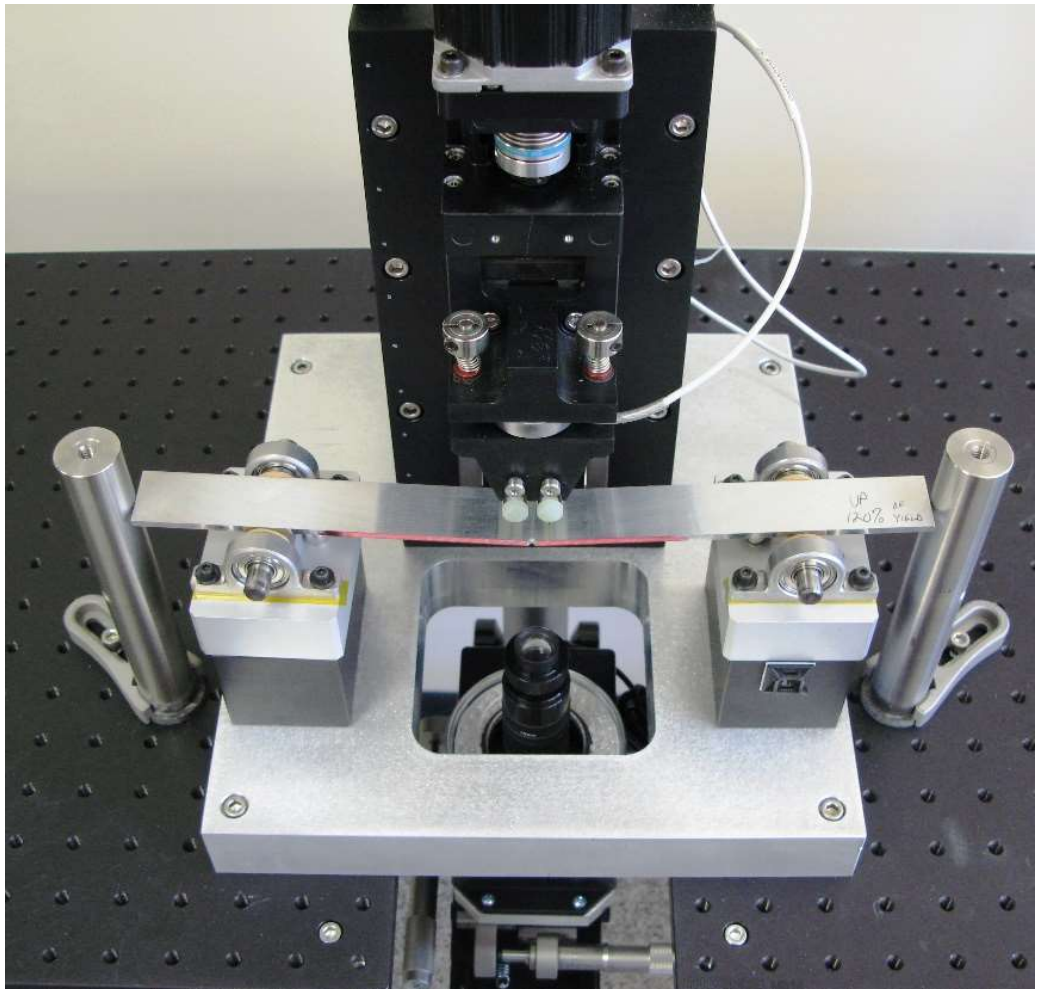


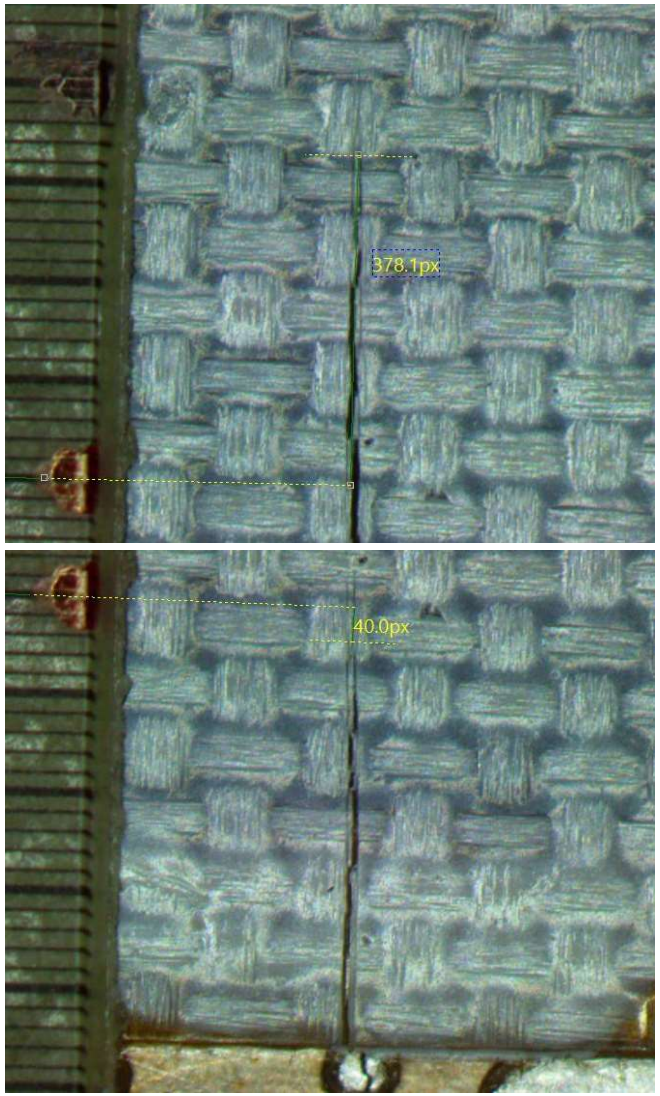
Automated 4-Point Test Bending Rig

- 1” between inner rollers, 8” between outer rollers
- Constant moment between inner rollers, 3000 με (80% yield)
- Cycles at 1Hz while collecting load, stroke, temp, CNT resistance



Crack Imaging System





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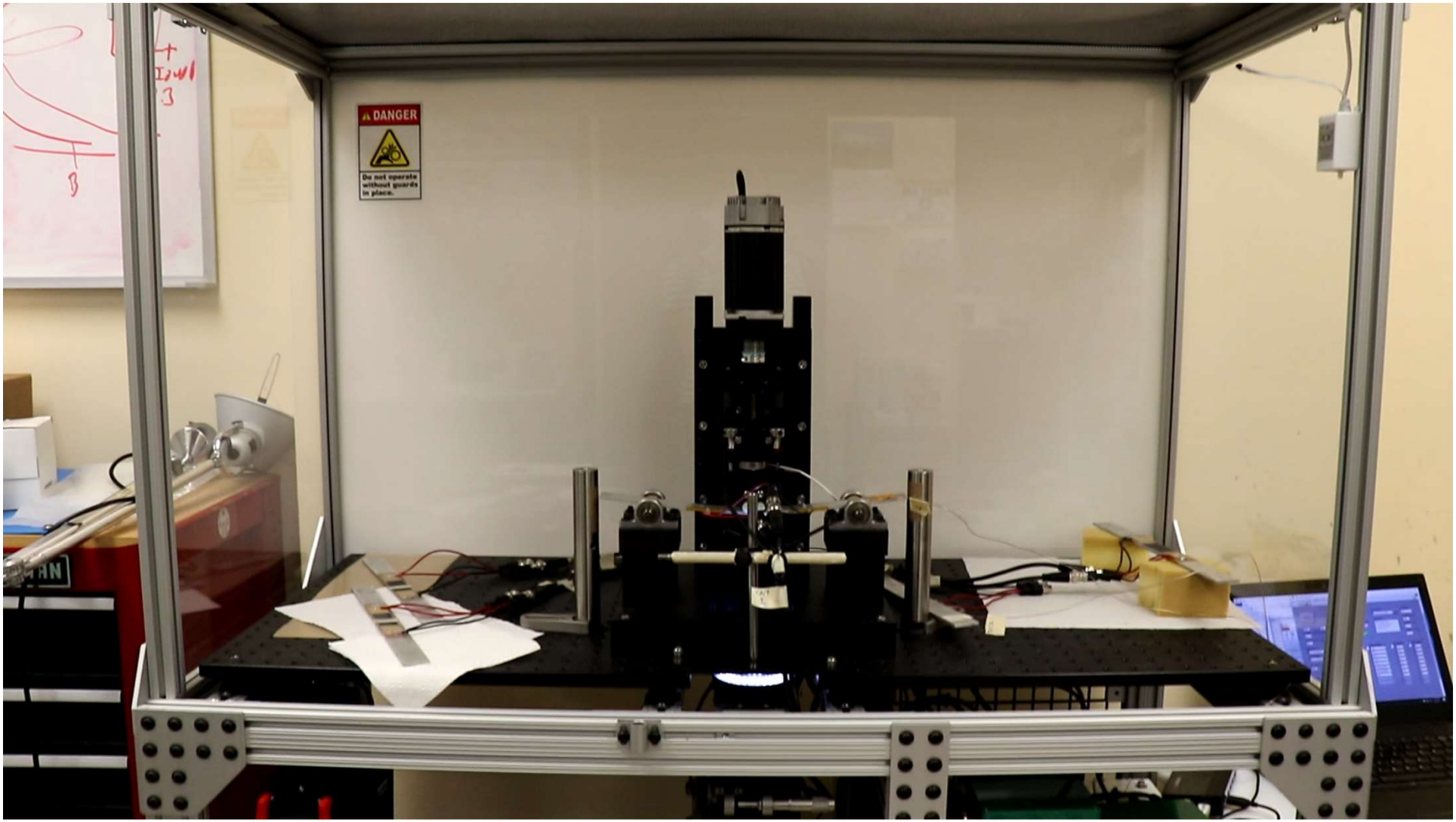
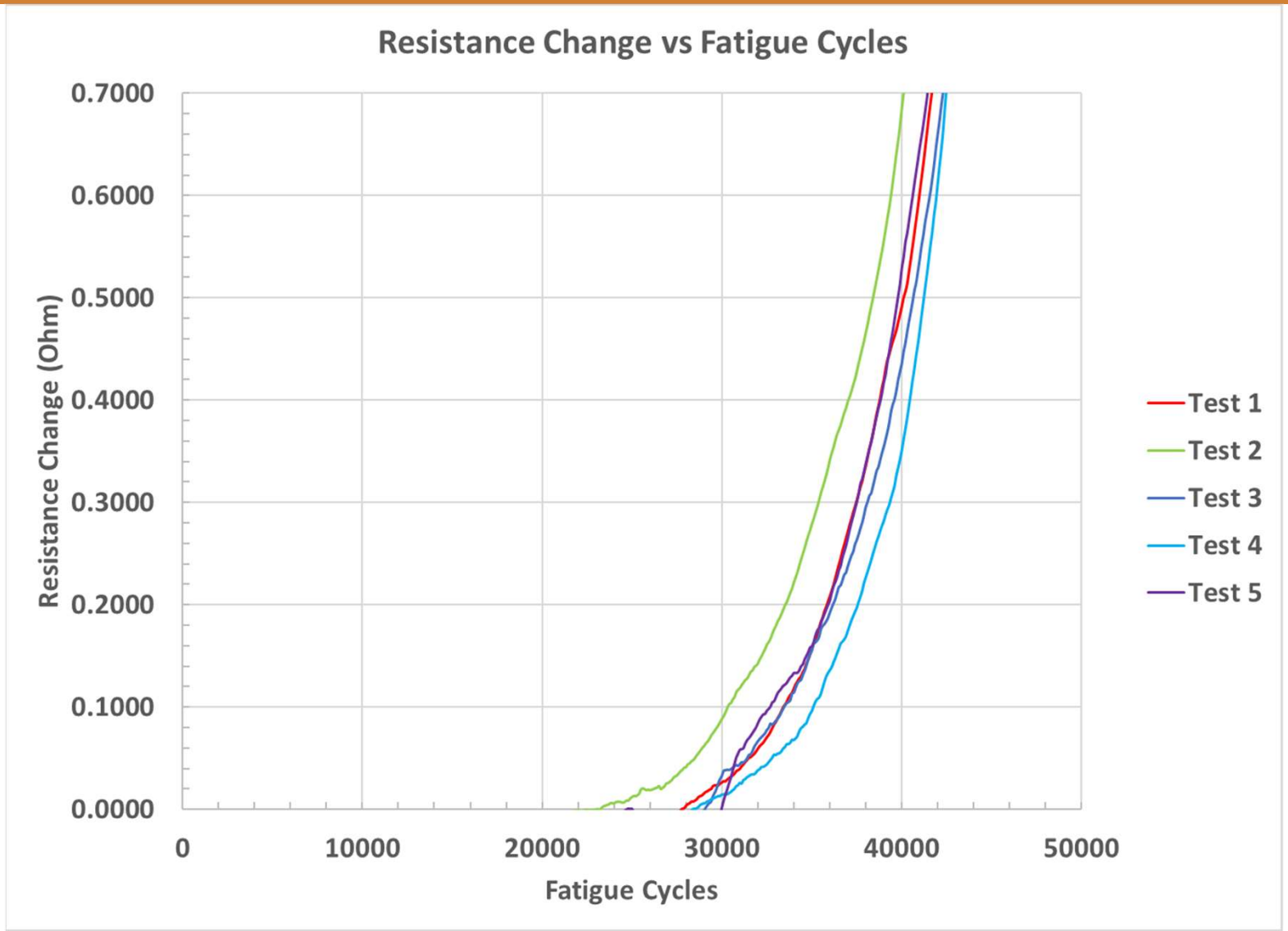
Continuum Crack Gauge Performance Assessment



Change in Resistance VS Fatigue Cycles



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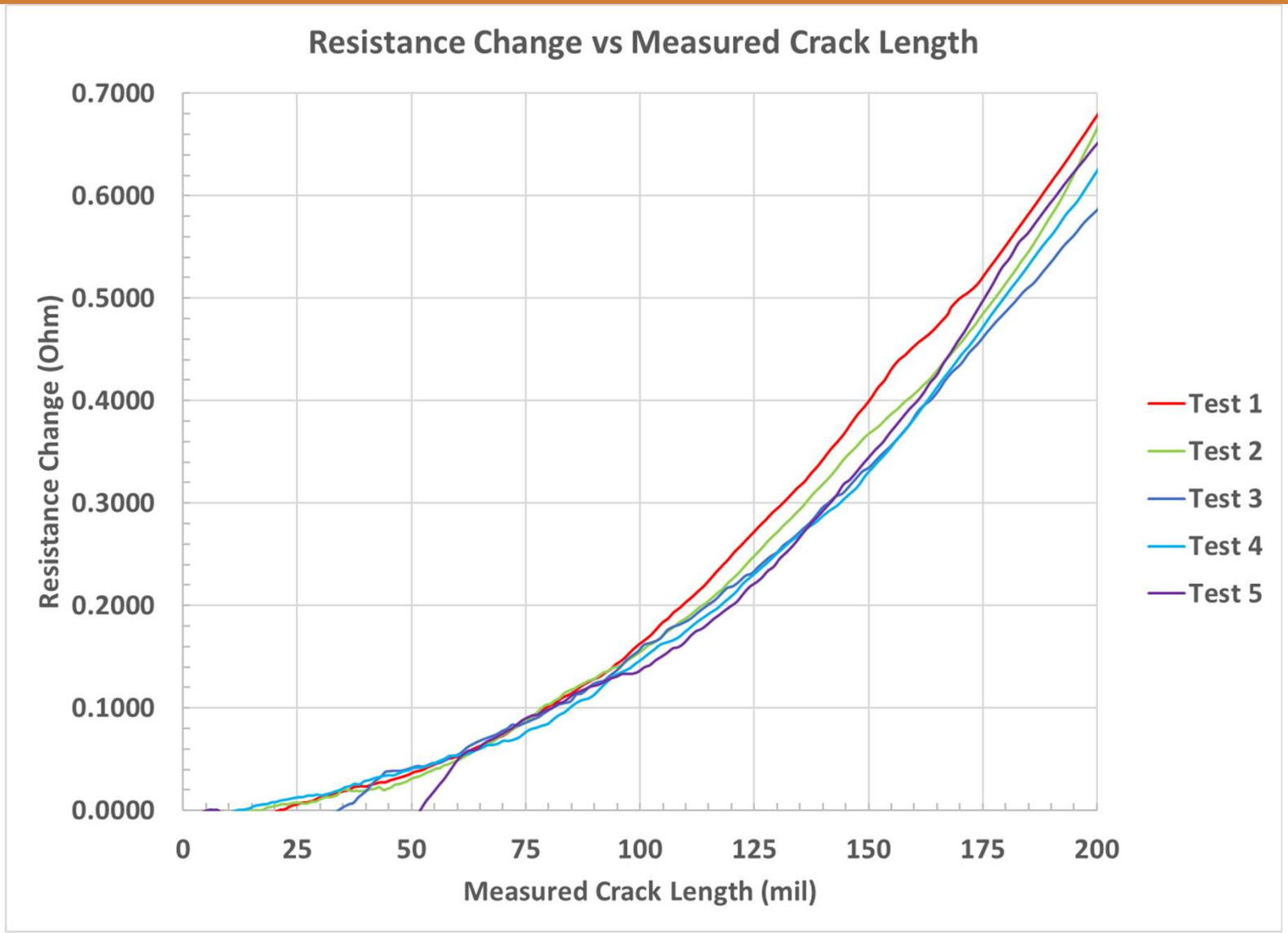
Change in Resistance VS Fatigue Crack Length



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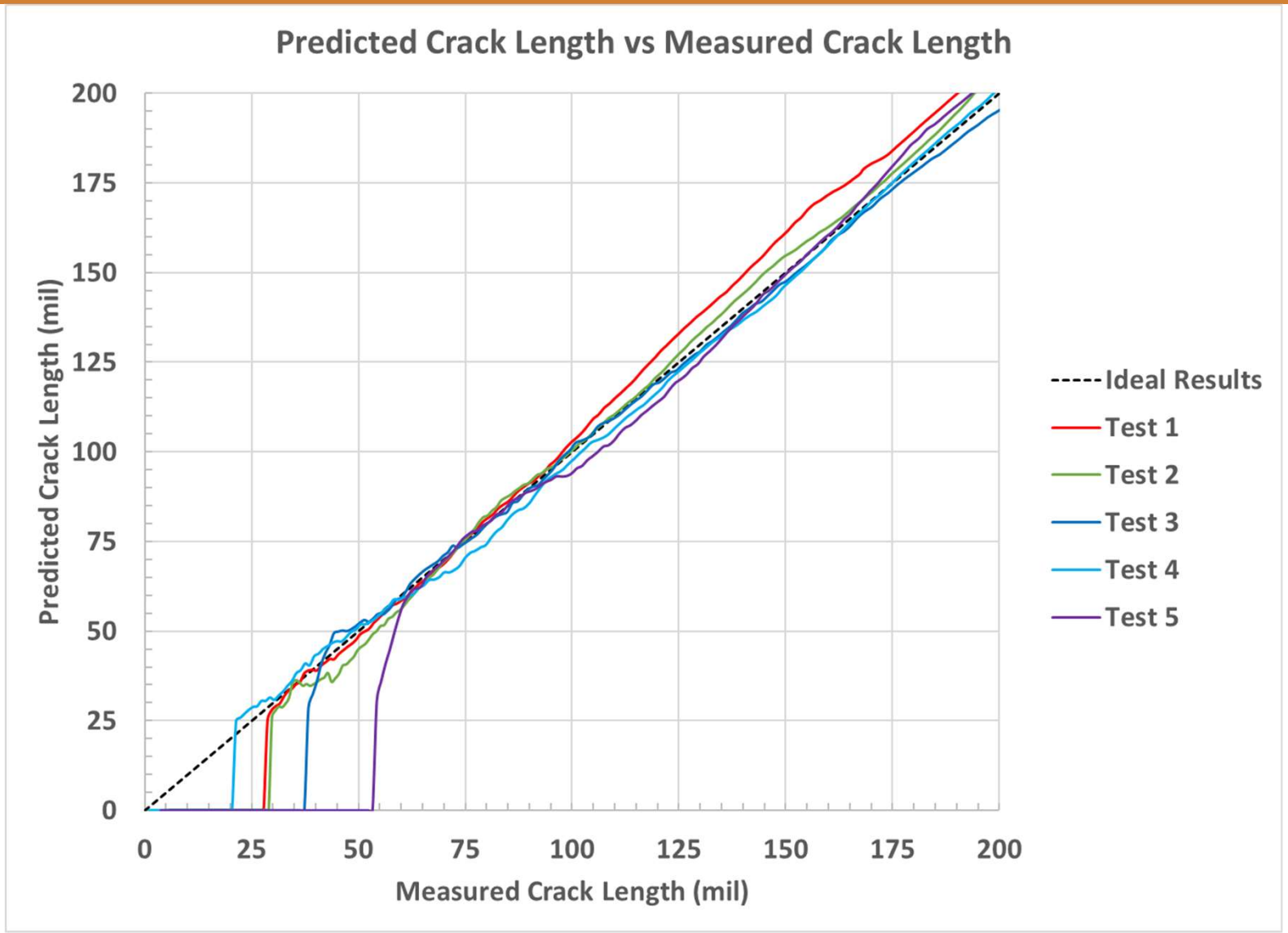
Comparison of Prediction to Measured Crack



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CNT Continuum Crack Gauge Summary

- Developed passive means for measuring fatigue crack growth
- CNT-based sensing element changes resistance with crack growth
- Excellent correlation between theory/model & calibrated cuts
- Good correlation between predicted & measured crack growth
- Method is simple and does not require a power source
- Provides a path to wireless sensing (see future work)

Future Research

- Probability of Detection Testing
  - More 4-pt bending specimens being manufactured for testing
  - Also testing at higher/lower temperatures & strain levels for variability
  - Analysis by Prof. Bill Meeker @ Iowa State U to assess statistical reliability

- RFID Integration
  - Co-developing hardware for wireless measurements w/Analog Devices
  - Will test with calibrated CNT cuts to assess accuracy
  - Will test with RFID configuration on fatigue specimen

- Blind Testing
  - Will demonstrate integrated RFID sensor on blind specimen(s)
  - Testing with AFRL @ WPAFB

Technical & Business Contact

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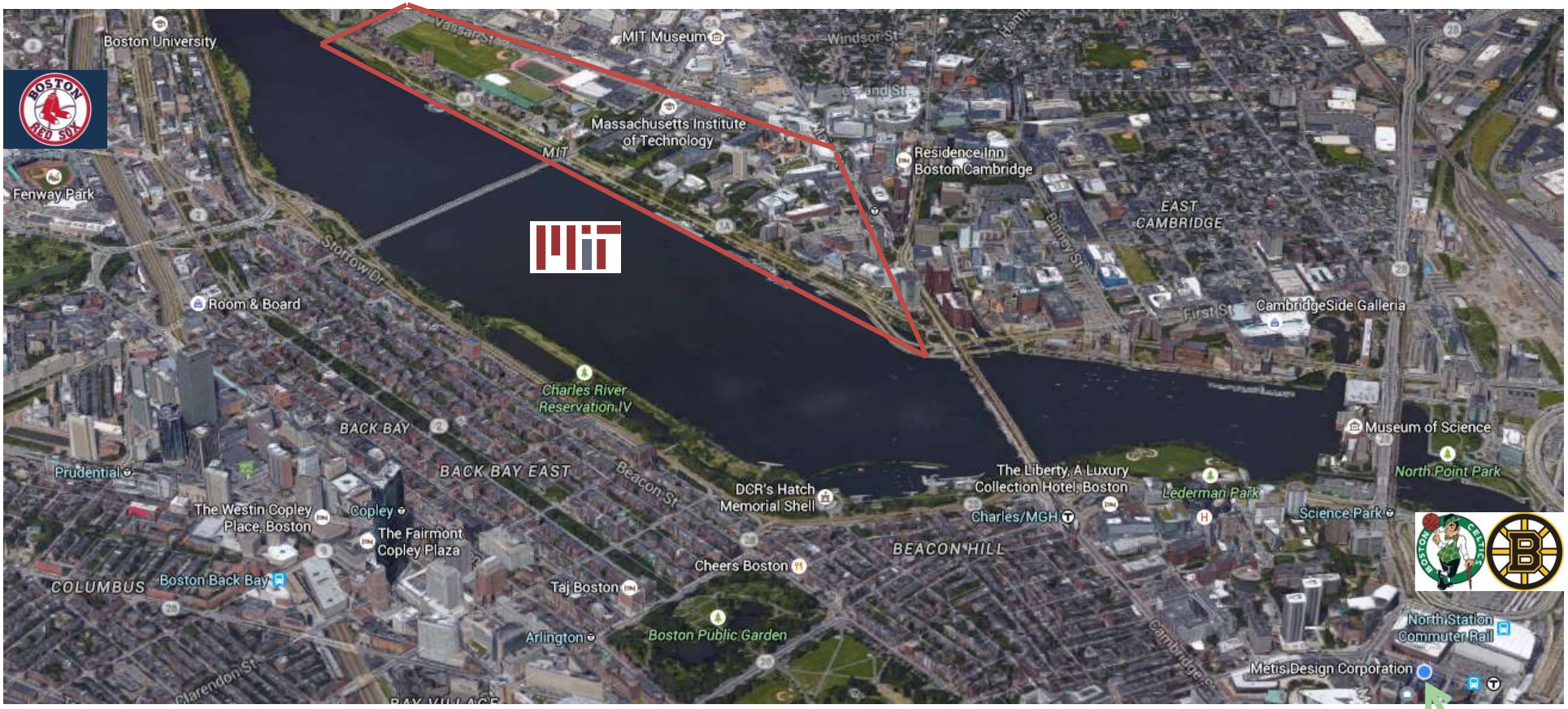

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