Experimental Evaluation of Soft Elastomeric Capacitive Sensors for Self-Sensing Tire Applications

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Introduction

- Soft elastomeric capacitors (SECs) are flexible sensors that detect deformation through changes in capacitance. Their flexibility allows them to conform to curved surfaces where conventional rigid sensors may be difficult to use. However, obtaining reliable measurements requires minimizing noise introduced by sensor installation and cable motion.
- This project looks at whether an SEC can be mounted inside a tire and used to detect deformation and good quality signals during compression testing.

Methods

- A cut tire was mounted in a custom 80/20 T-slotted aluminum test rig designed for vertical compression testing on the MTS machine.
- The fixture was placed in the MTS machine and loaded before sensor testing to check stability of the frame and clamping setup.
- A custom extended cable was soldered to the sensor so it could reach the external SEC DAQ board during MTS testing.
- A resistor was soldered in series with the SEC sensor leads so the sensor could be read within the DAQ measurement range.
- The cable and wires were secured to the tire surface to reduce motion-induced measurement noise.

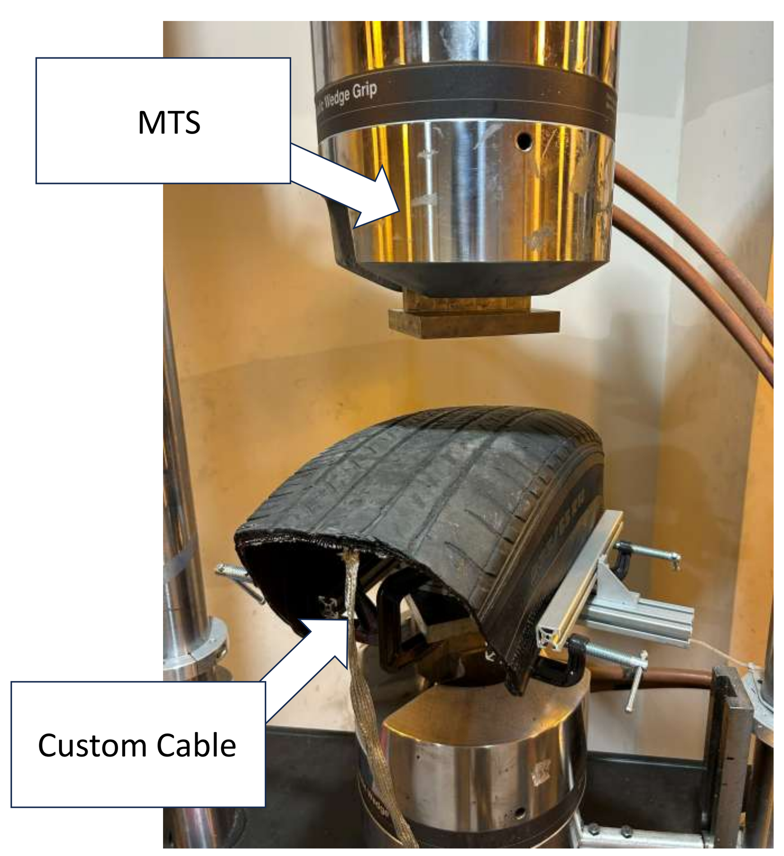

Figure 1: *MTS setup*

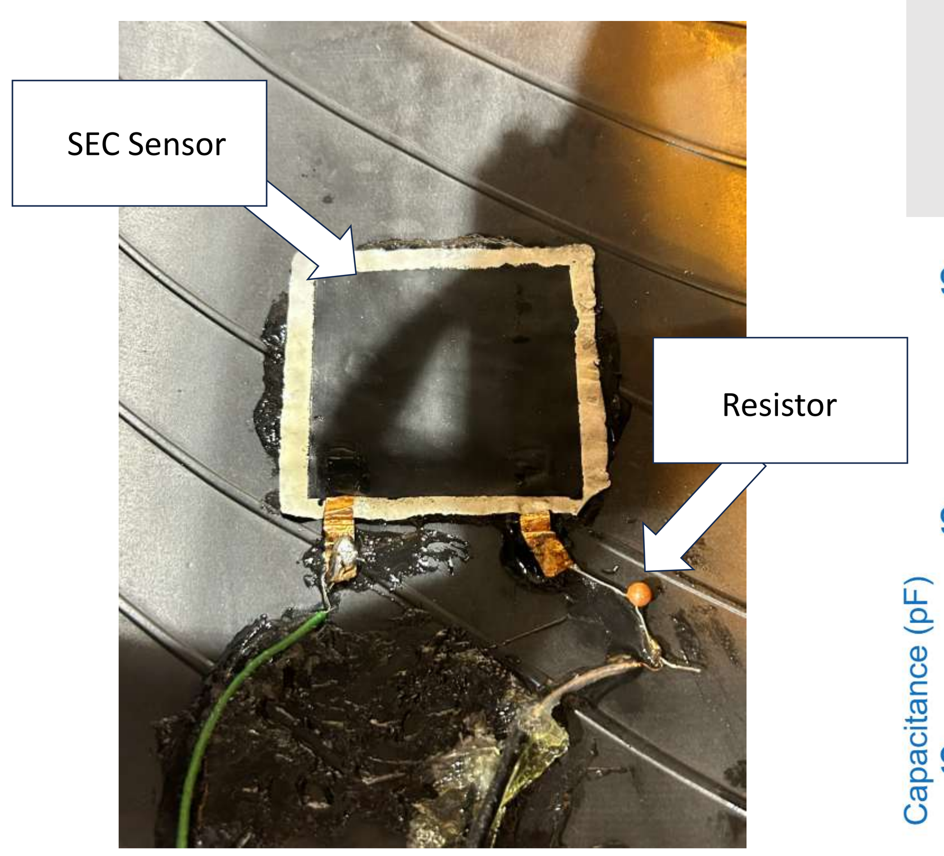

Figure 2: *SEC bonded inside the tire.*

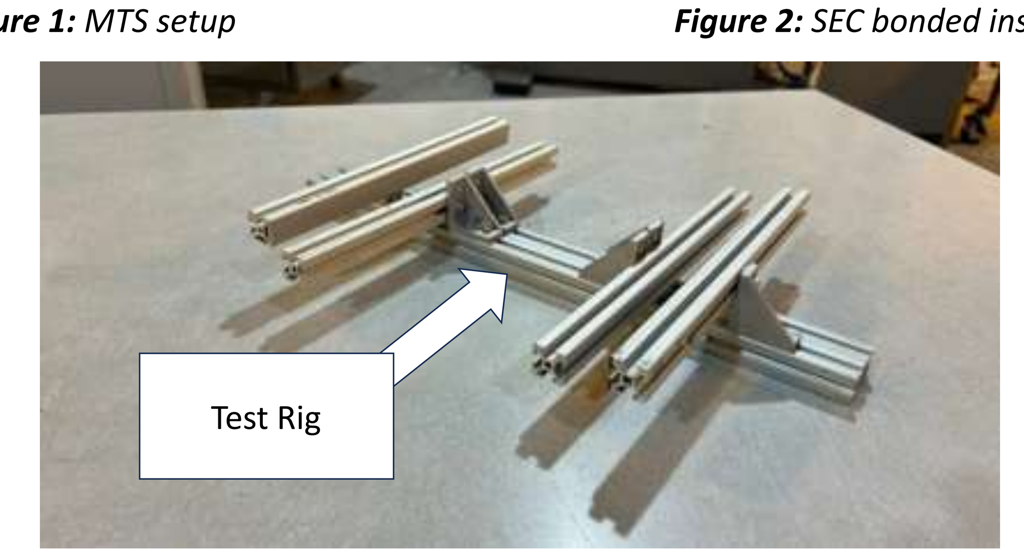

Figure 3: *Custom-built tire test rig.*

Significance

- Embedding SECs inside tires could enable soft, flexible sensing of tire deformation without adding rigid sensors that interfere with tire motion. In addition to tire sensing, the experimental procedures developed in this work can support future research involving SEC characterization and integration into other flexible sensing applications. This work lays the foundation for comparing SEC capacitance changes with MTS load and displacement data, moving toward self-sensing tire systems.

Results

- The tire fixture was tested under preliminary loading. The frame and clamps held the tire securely up to approximately 85 lbf, with no visible fixture failure.
- A maximum compressive load of approximately 73 lbf was reached before the onset of the first tire break.
- A distinct change in capacitance of approximately 0.03 pF was observed near the onset of the first tire break, occurring at approximately the same point where the measured force reached its maximum value and began to decrease.
- Preliminary results show that the SEC capacitance changes throughout the compression test as the applied force and displacement increase, demonstrating that the sensor is responsive to tire deformation.

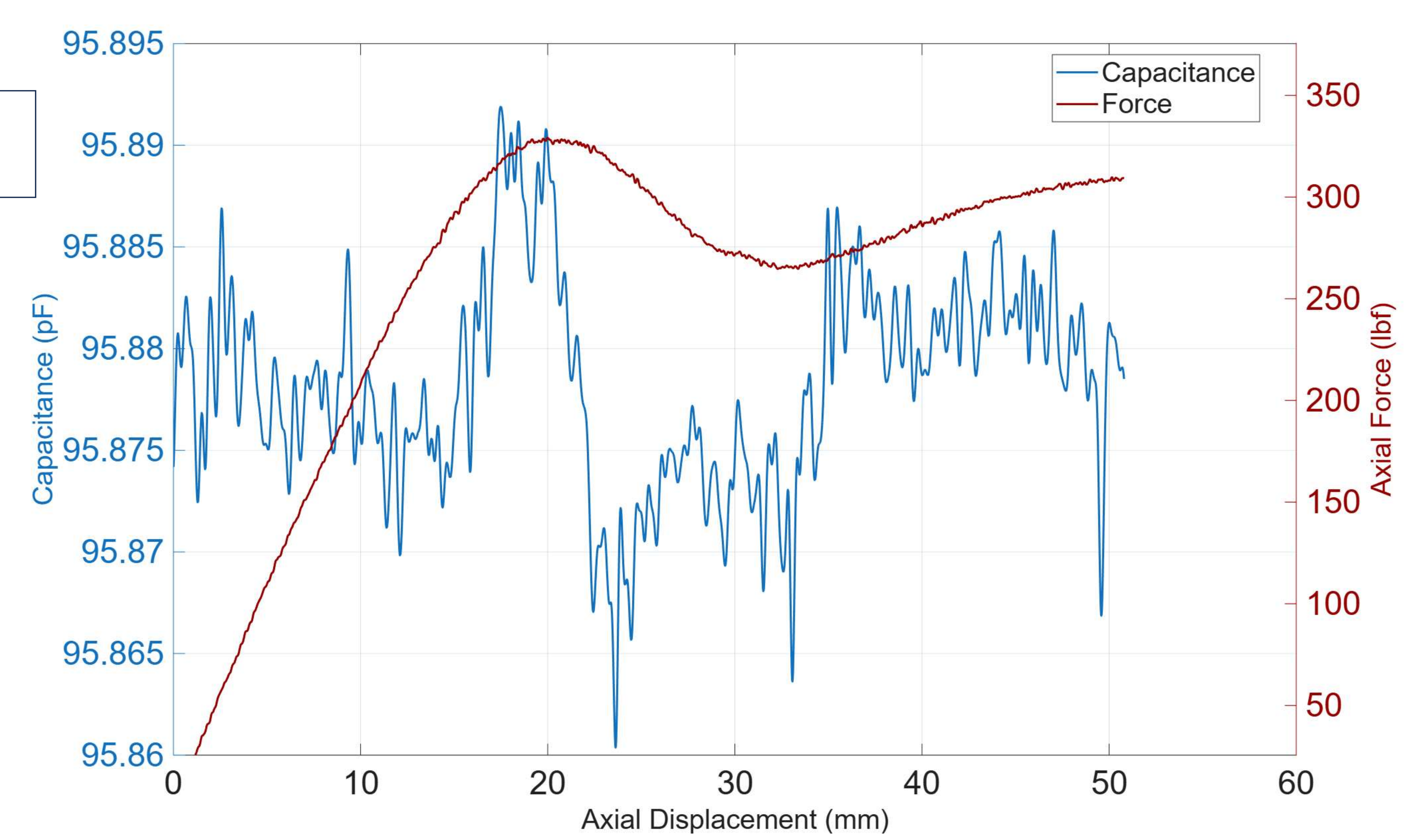

Figure 4: *Filtered SEC capacitance (blue) and MTS axial force (red) plotted as a function of tire compression displacement during the first tire compression test (t=60s)*

Conclusion

- The custom 80/20 tire test rig remained stable under preliminary loading.
- The addition of a series resistor enabled successful SEC measurements using DAQ Range 4.
- Cable motion introduced noise into the capacitance measurements across all test trials.
- SEC exhibited measurable capacitance changes in response to tire deformation.

Next Steps

- Run controlled compression tests on the MTS machine while recording capacitance from the SEC. The main goal is to determine whether the capacitance changes consistently as the tire is loaded and unloaded.
- Test triaxial cables with different thicknesses to determine which is least susceptible to cable movement and produces the most accurate sensor measurements.
- Correct the DAQ-reported capacitance because the series resistor affects the measured values:

$$C_{SEC} = \frac{1}{\sqrt{\frac{1}{C_{read}^2} - (2\pi f R)^2}}$$

- Analyze the corrected data using capacitance change:

$$\Delta C_{SEC} = C_{SEC} - C_0$$

- Compare ΔC_{SEC} with MTS load and displacement to determine whether the sensor response tracks tire deformation.

References

- Austin R.J. Downey. *SEC DAQ Open-Source Hardware Design*. GitHub, April 2018. https://github.com/ARTS-Laboratory/SEC-DAQ-Open-Source-Hardware-Design
- Emmanuel A. Ogunniyi, Han Liu, Austin R. J. Downey, Simon Laflamme, Jian Li, Caroline Bennett, William Collins, Hongki Jo, Paul Ziehl, "Soft elastomeric capacitors with an extended polymer matrix for strain sensing on concrete," Proc. SPIE 12486, Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2023, 1248618 (18 April 2023); https://doi.org/10.1117/12.2658568

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