Industrial Capacitance Sensors and Actuators

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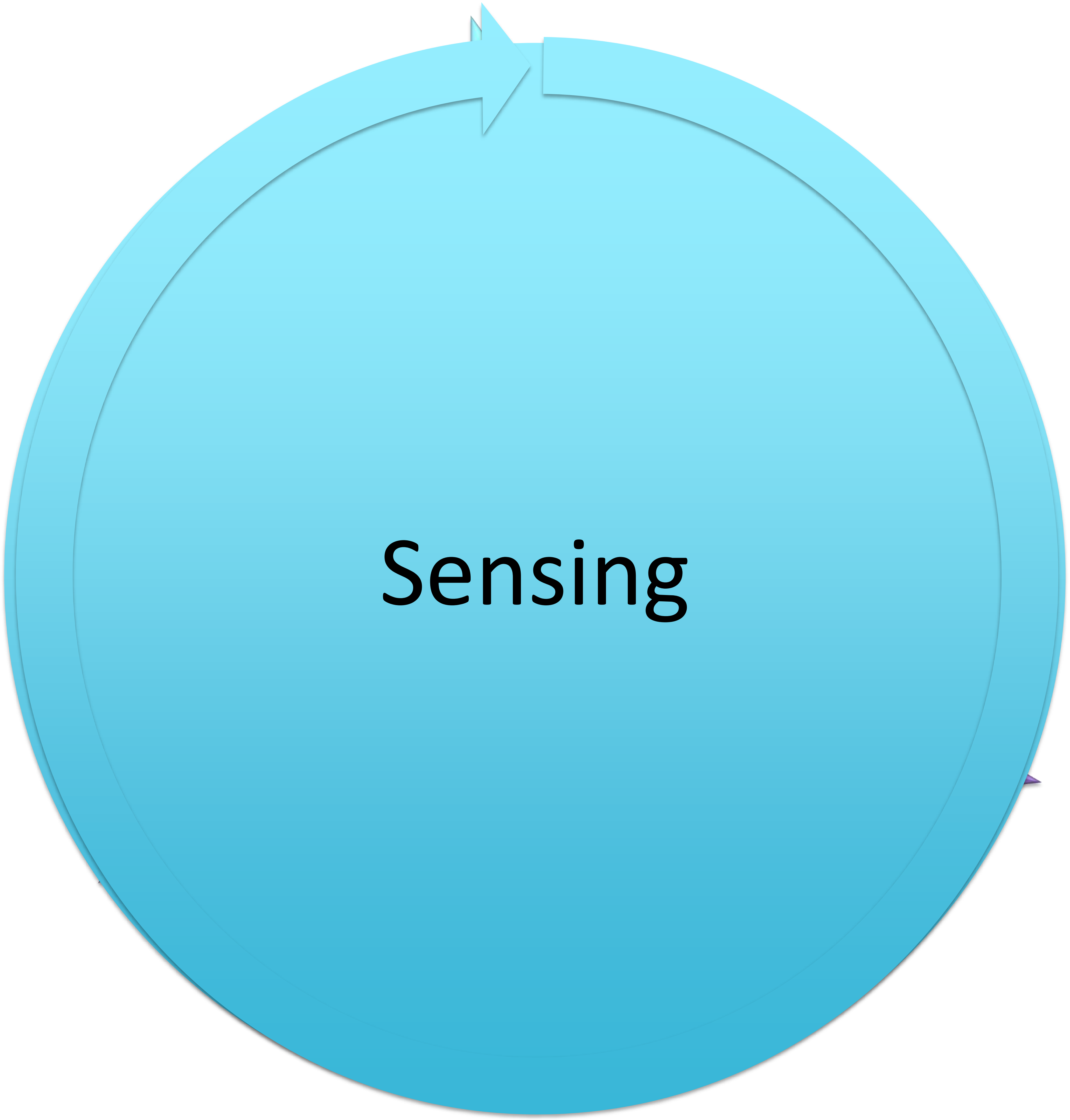
PROBLEM STATEMENT

PROBLEM: Component failures causing machine and personnel safety risks.

GOAL: To provide an in-line and minimally invasive means for monitoring industrial component health to prevent catastrophic disasters and a method for at least temporarily mitigating failure.

IMPACT: Increased Safety for Operators and Equipment
Cost Savings
Scheduled Maintenance/Down-time

PROCESS FLOW



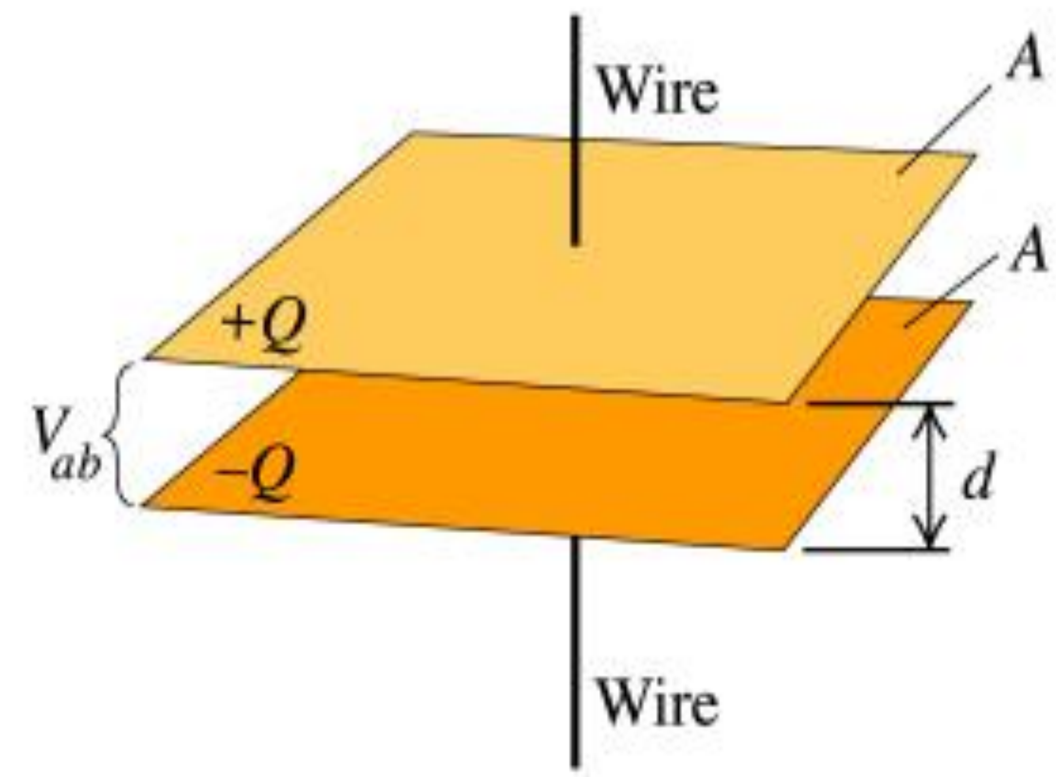
CAPACITIVE SENSING

Pros

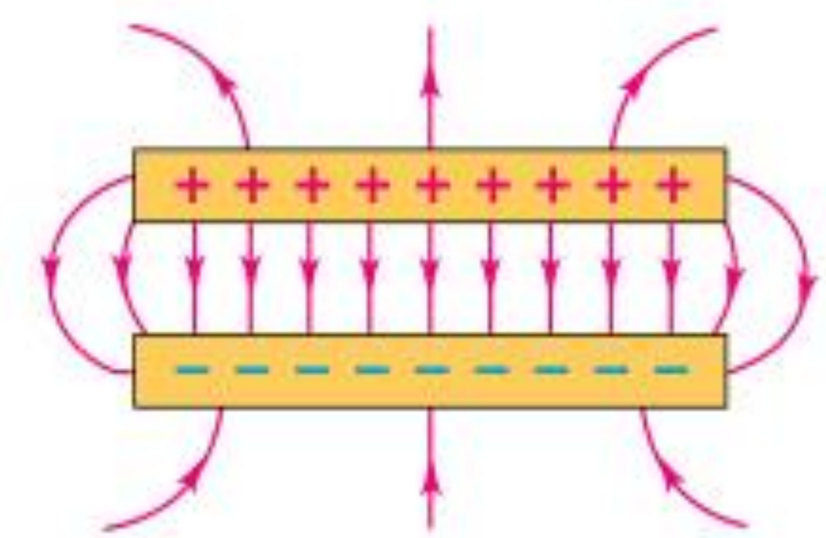
- Temperature effects on dielectric properties are low
- Capacitors can be made from a variety of materials
- Extremely sensitive (picoFarad range)
- Applicable to a variety of systems

Cons

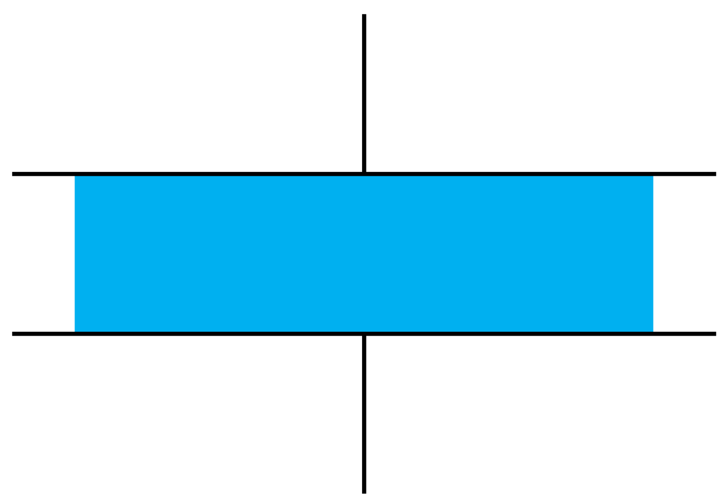
- Sensitive to fringe effects or stray capacitance
- Overall resistance between the conductive plates must remain high



(a)


(b)

HOW IT WORKS…



Parallel Plate Capacitor

$$C = \varepsilon \frac{\varepsilon_o A}{d}$$

A = conductive plate area

d = distance between infinite parallel plates

ε = dielectric constant of the center material

ε_o = permittivity of free space

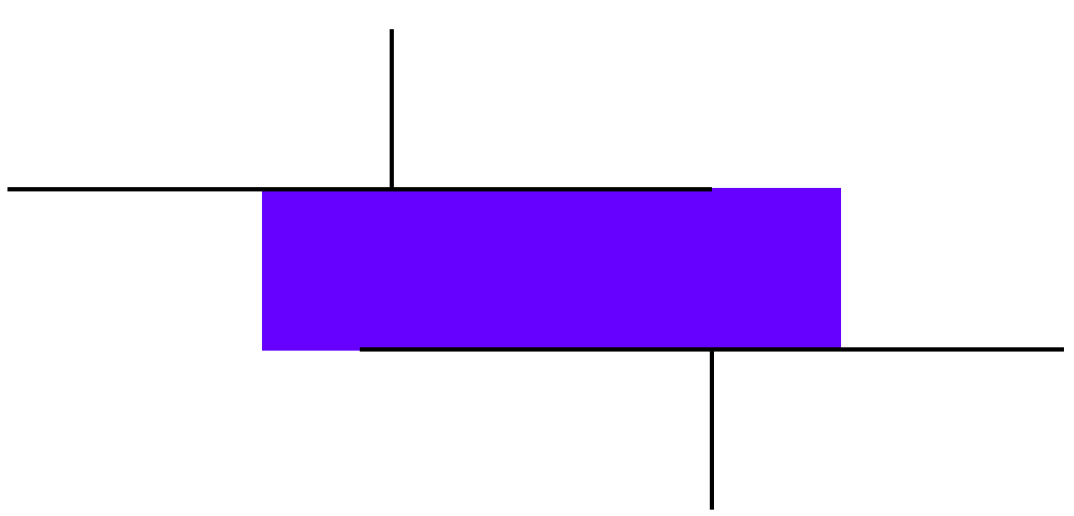
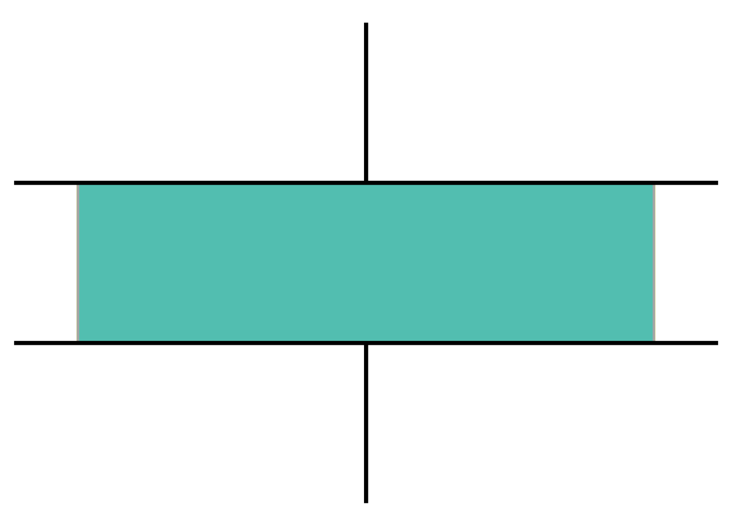
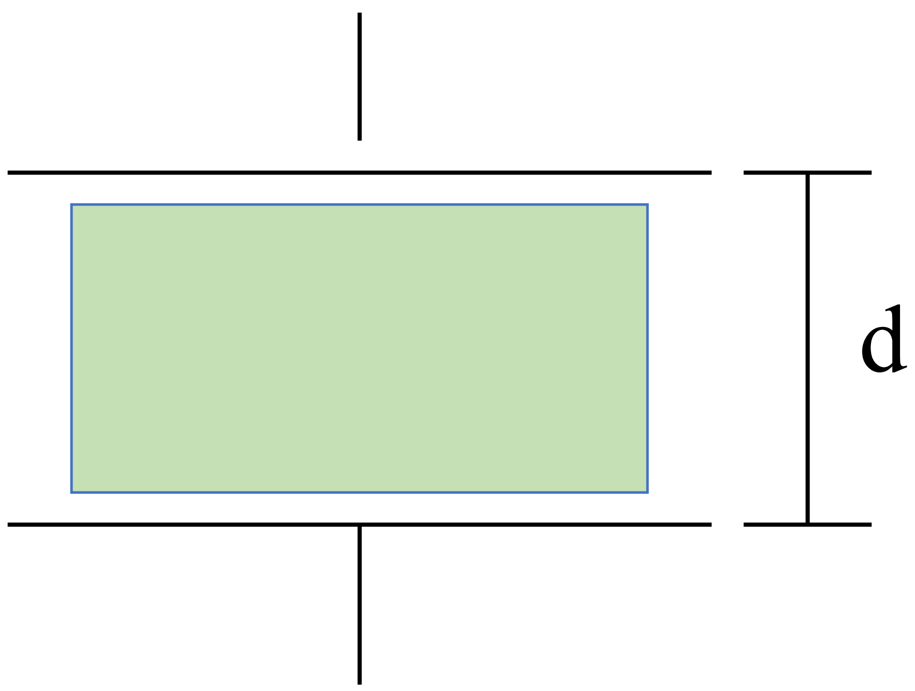


Plate Area Change



Change in Dielectric

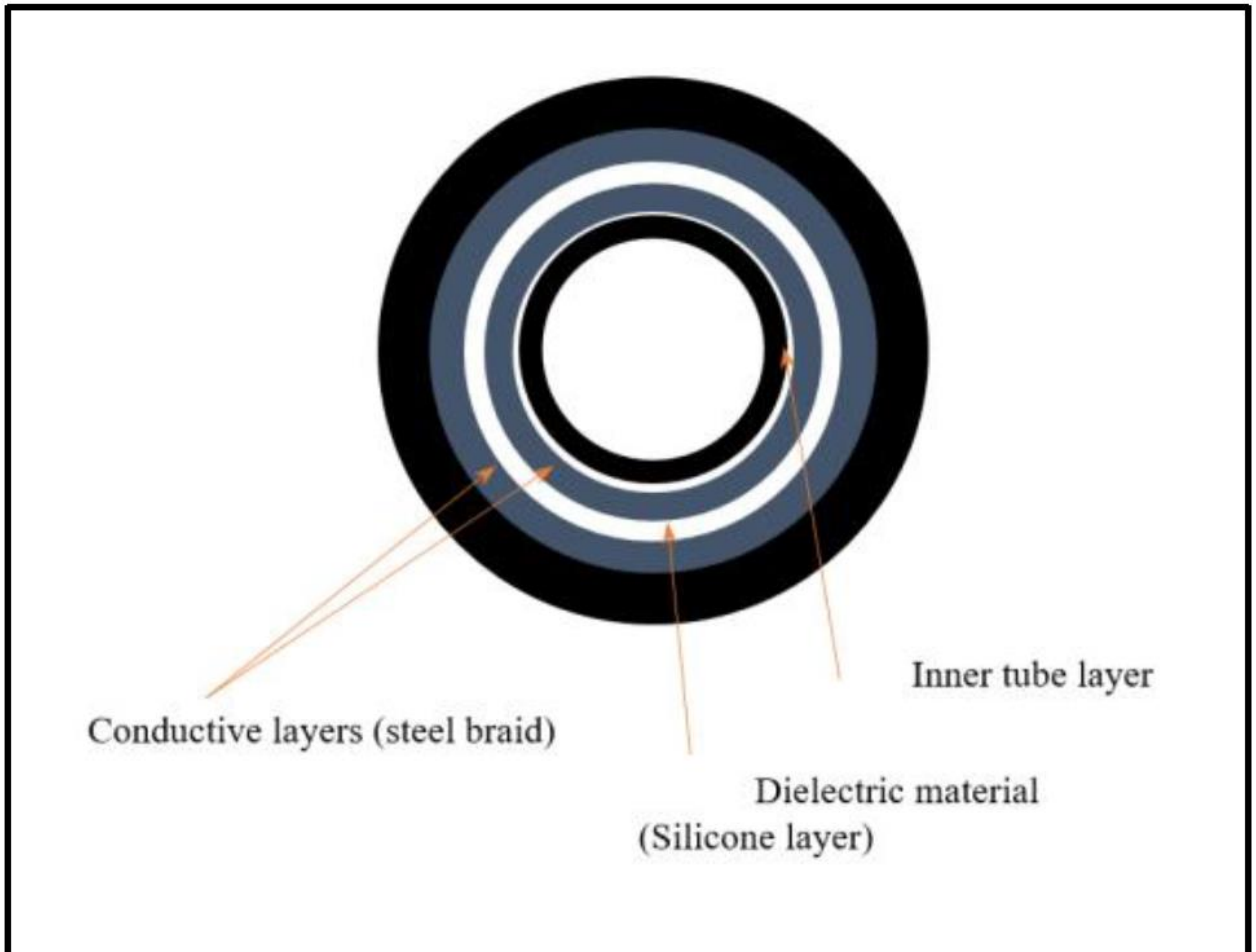


Change in plate distance

INDUSTRIAL APPLICATIONS

- Hydraulic Hoses Hydraulic Hoses
- Tires
- O-rings/Seals
- V-belts

CYLINDRICAL CAPACITOR

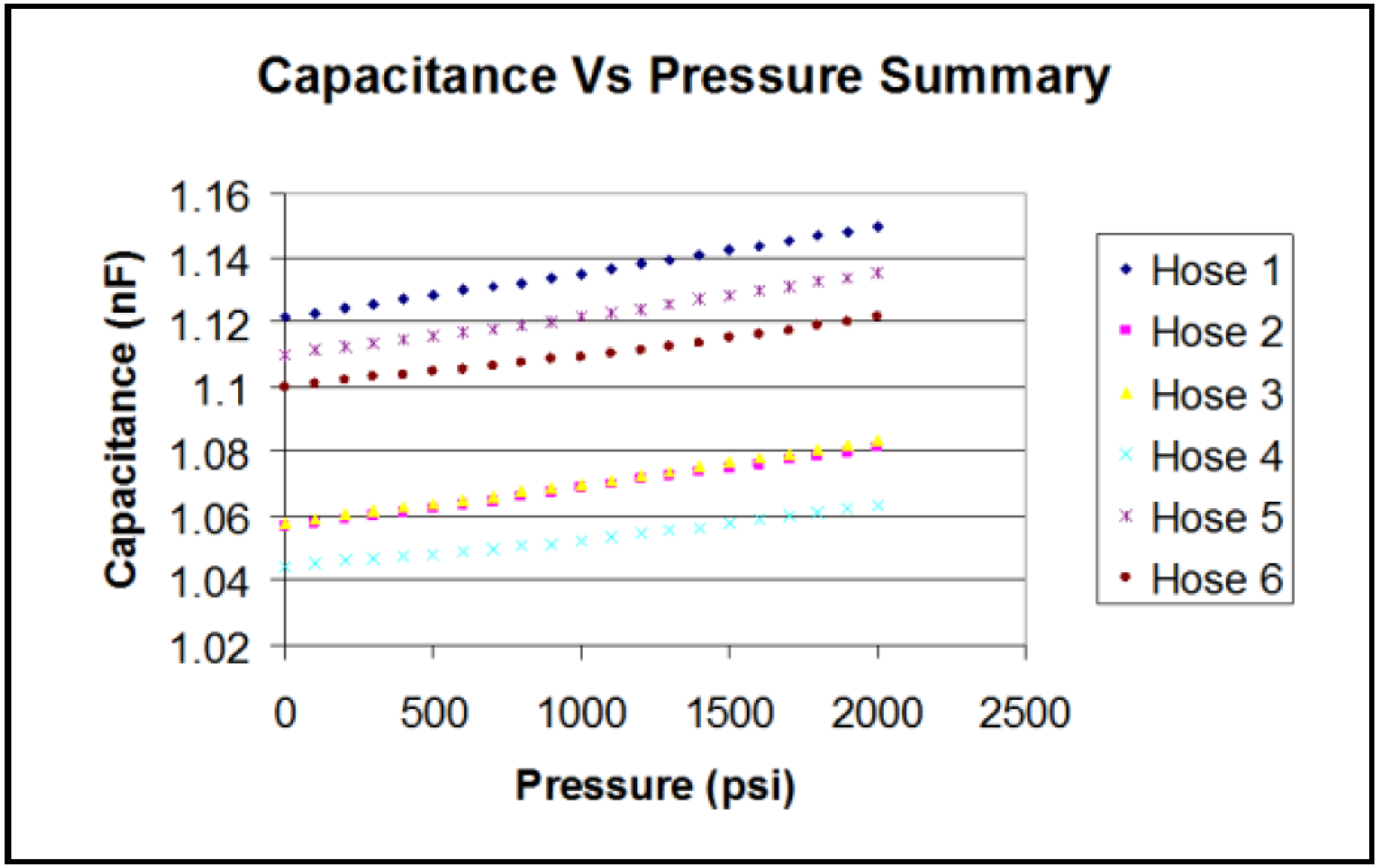


$$C = \frac{2\pi \mathcal{E}_o \varepsilon L}{ln\left(\frac{b}{a}\right)}$$

Krutz, Gary and Deckard, Aaron. “Hydraulic Hose with Integral Life-Sensing Capability and Method Therefor” US Patent 75559364B2 2009.

STATIC TESTING

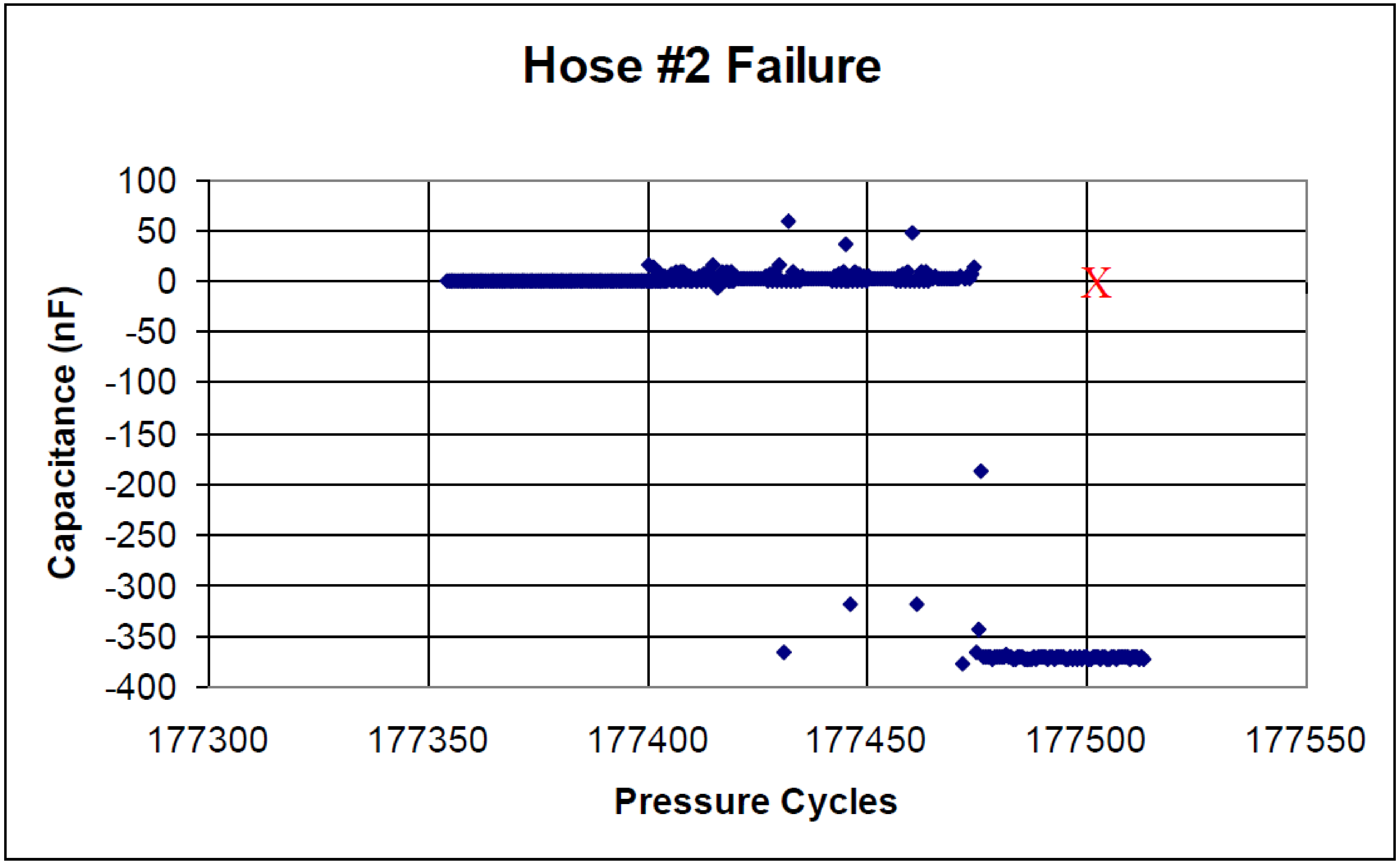
- 6 hoses tested under static load using a deadweight tester.
- Capacitance was measured every 100 psi from 0 psi to 2000 psi



Krutz, Gary and Deckard, Aaron. "Hydraulic Hose with Integral Life-Sensing Capability and Method Therefor" US Patent 75559364B2 2009.

DYNAMIC TESTING

- 6 hoses were testing on a cyclic pressure tester until failure.
- Capacitance measurements were 2.8 samples/min.



Krutz, Gary and Deckard, Aaron. “Hydraulic Hose with Integral Life-Sensing Capability and Method Therefor” US Patent 75559364B2 2009.

CONTINUED TESTING

- Eaton Corporation tested the hoses on 40 refuse vehicles beginning in Oct. 2011.
- To date Eaton has received 38 alerts
    - 27 abrasion
    - 9 fatigue
    - 2 external damage
- Zero failures have occurred in the field as a result.


Products & Services | Customer Support | Sustainability | Our Company

LifeSense

Know the moment your hydraulic hose needs attention.

Introducing Eaton's LifeSense™ a patented hydraulic hose condition monitoring technology. LifeSense™ monitors the health of hydraulic hose assemblies. As the hose assembly approaches the end of its useful life, LifeSense™ detects events occurring within the hose that have been shown to lead to failure and notifies the designated individual that the hose needs to be replaced. This notification is provided with enough time to replace the hose during planned maintenance prior to failure thus saving downtime, clean-up costs, environmental damage and potential injury.

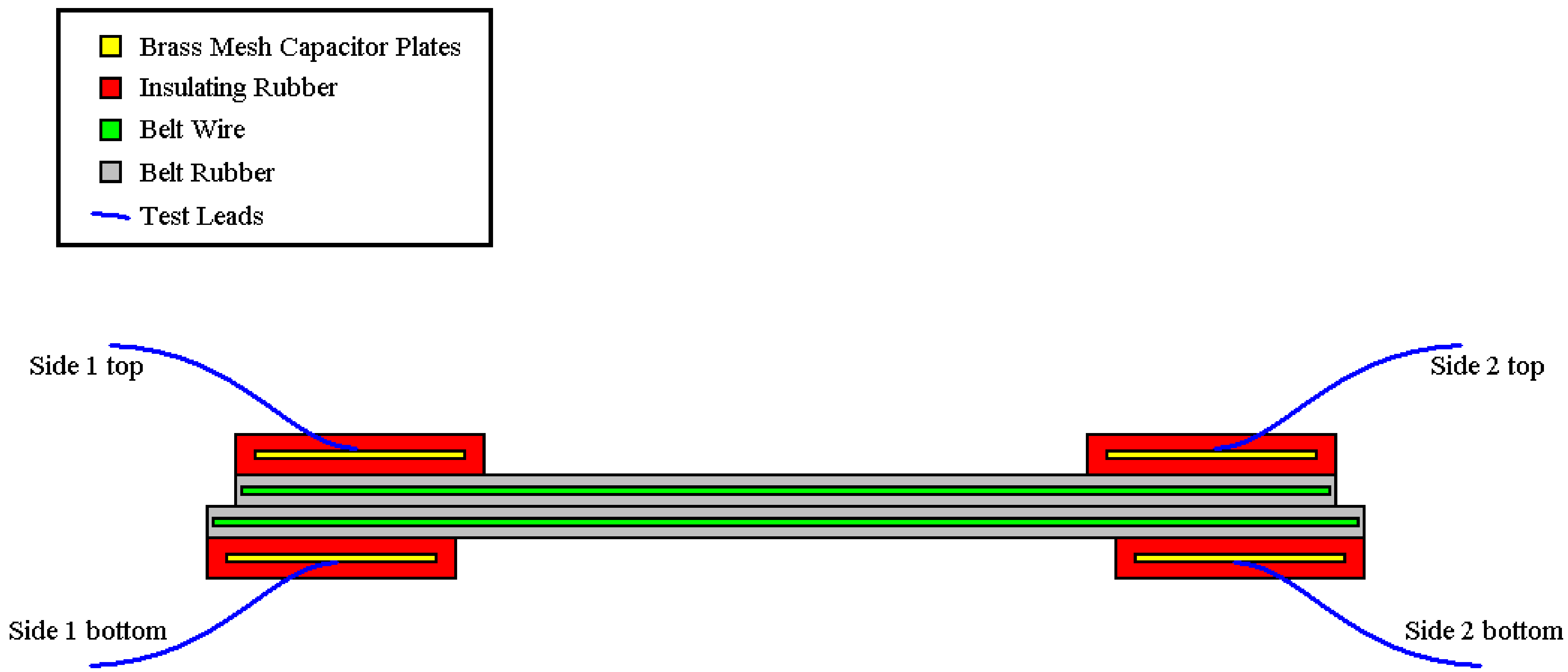
INDUSTRIAL APPLICATIONS

Tires

- Hydraulic Hoses
- Tires
- O-rings/Seals
- V-belts

TIRE CAPACITORS

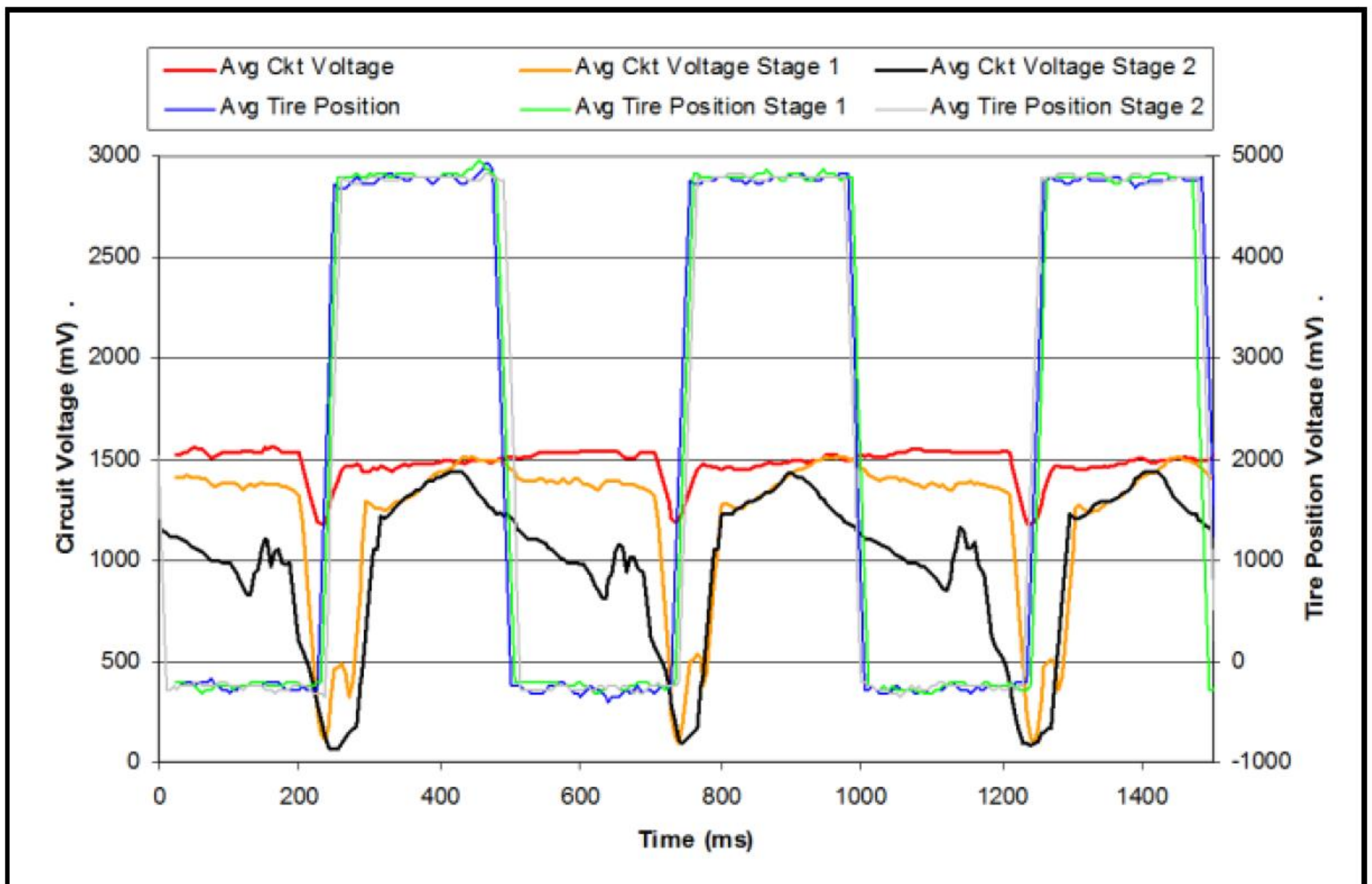
- Metal wire mesh was added to both shoulder in a similar configuration to steel belts.
- The size of the capacitor can be controlled through the mesh.



Krutz, Gary, Harmeyer, Keith, and Holland, Michael. "Structures with Integral Life-sensing Capability." US Patent 7752904B2 2010.

TIRE RESULTS

- Tire capacitance was measured while tires rotated on a rolling resistance stand.
- Tire capacitance is cyclical due to tire rotation.
- Two levels of gap damage were introduced and tire capacitance monitored.



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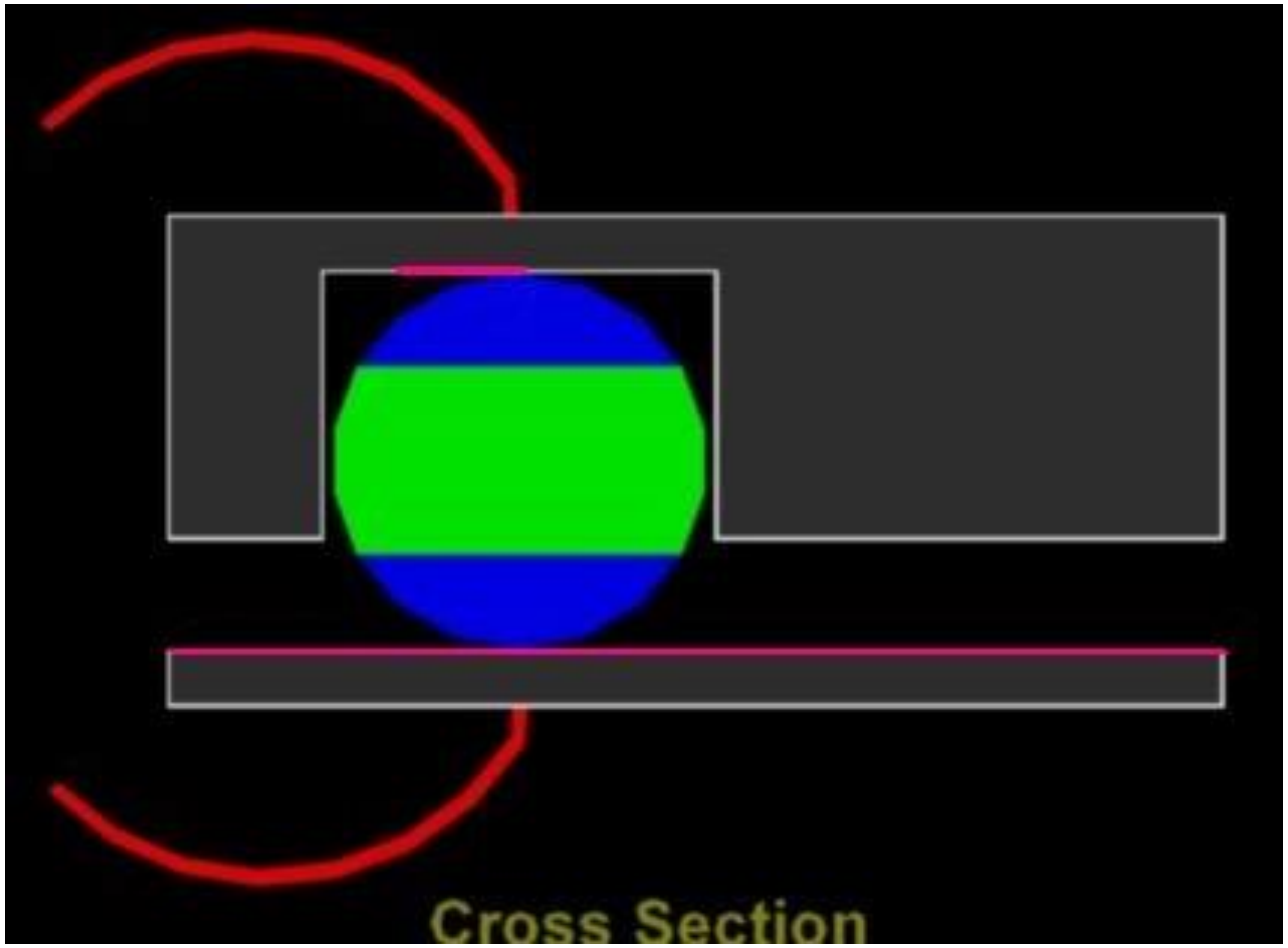
INDUSTRIAL APPLICATIONS

- Hydraulic Hoses

O-rings/Seals

- Tires
- O-rings/Seals
- V-belts

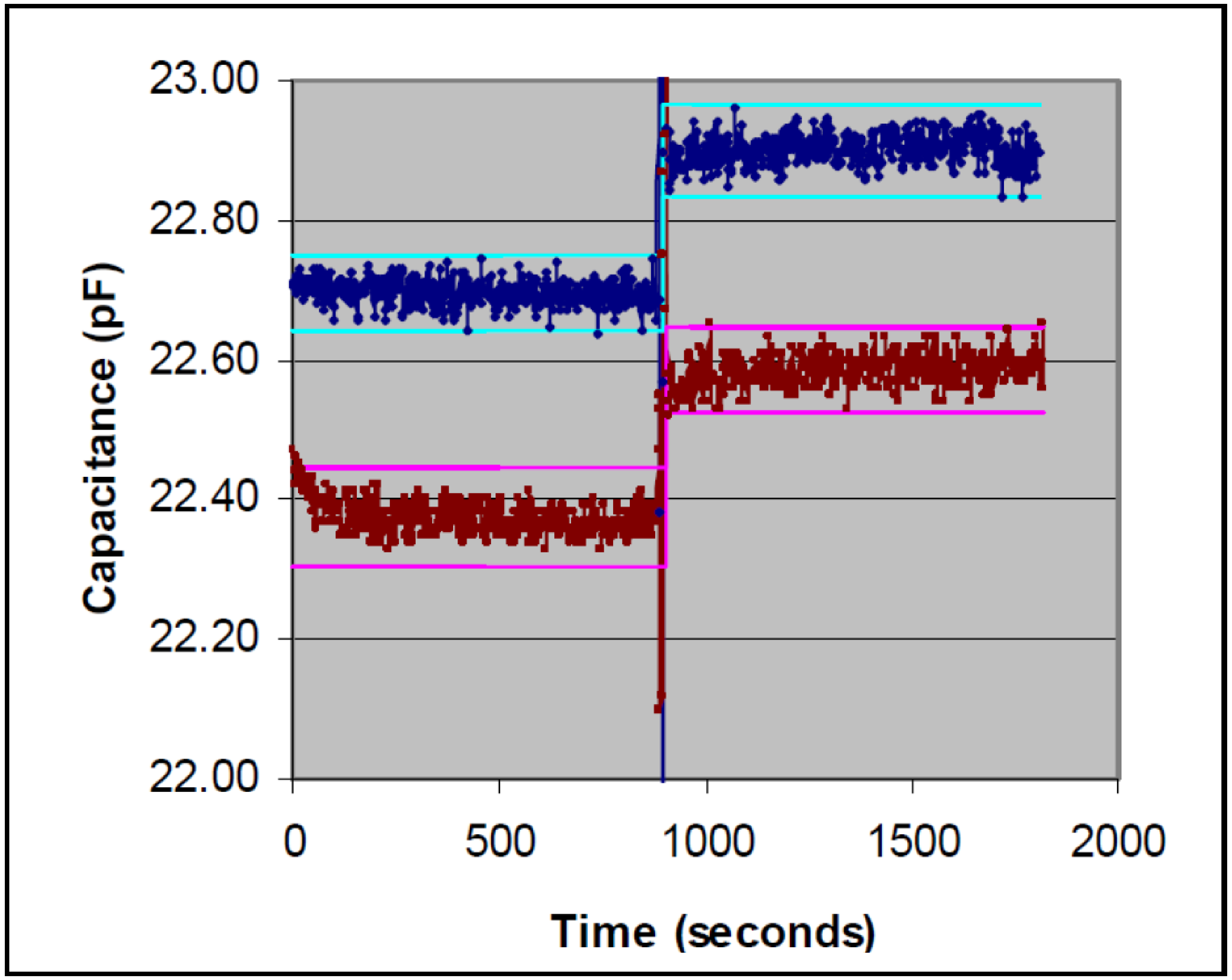
O-RING CAPACITOR CONSTRUCTION

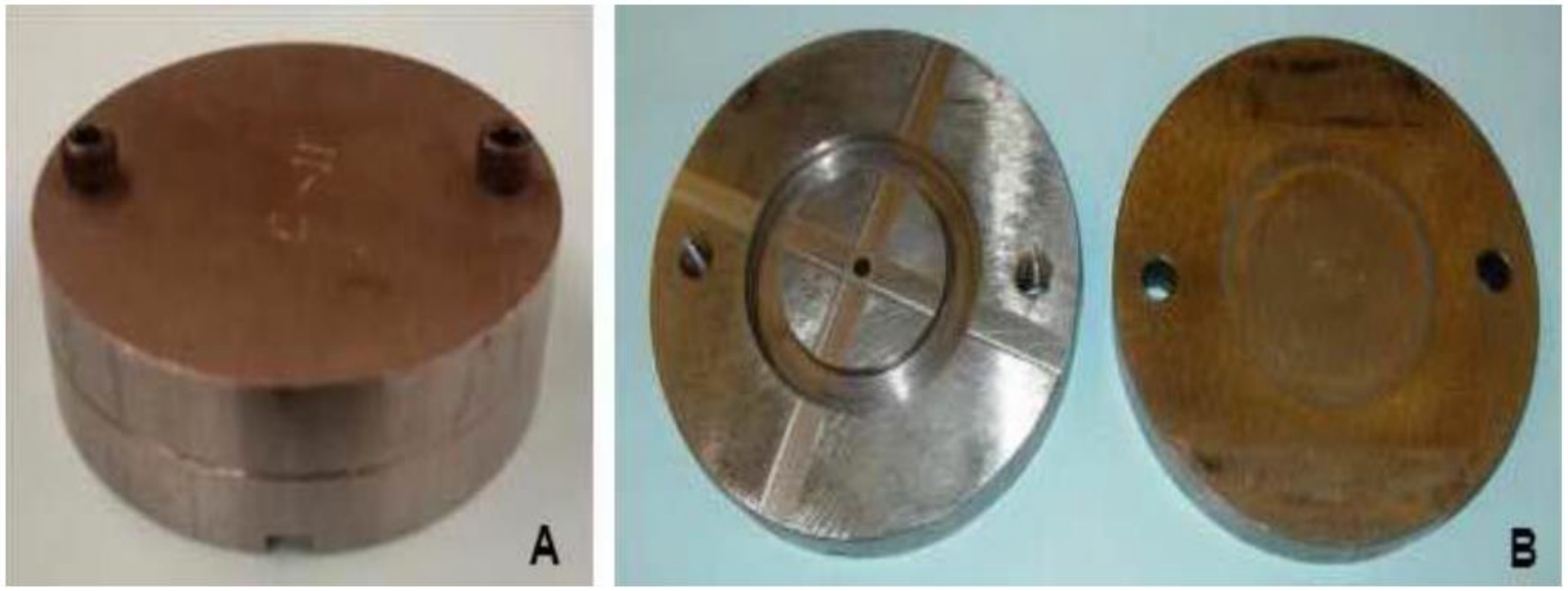


- O-ring capacitors were constructed on all polymer materials
- Conductive particle enhanced electrode layers and inherently dielectric polymer layers.

Krutz, Gary, Harmeyer, Keith, Holland, Michael, and Gallien, Timu. "Polymeric Structures and Methods for Producing and Monitoring Polymeric Structures" US Patent 7977952 2011.

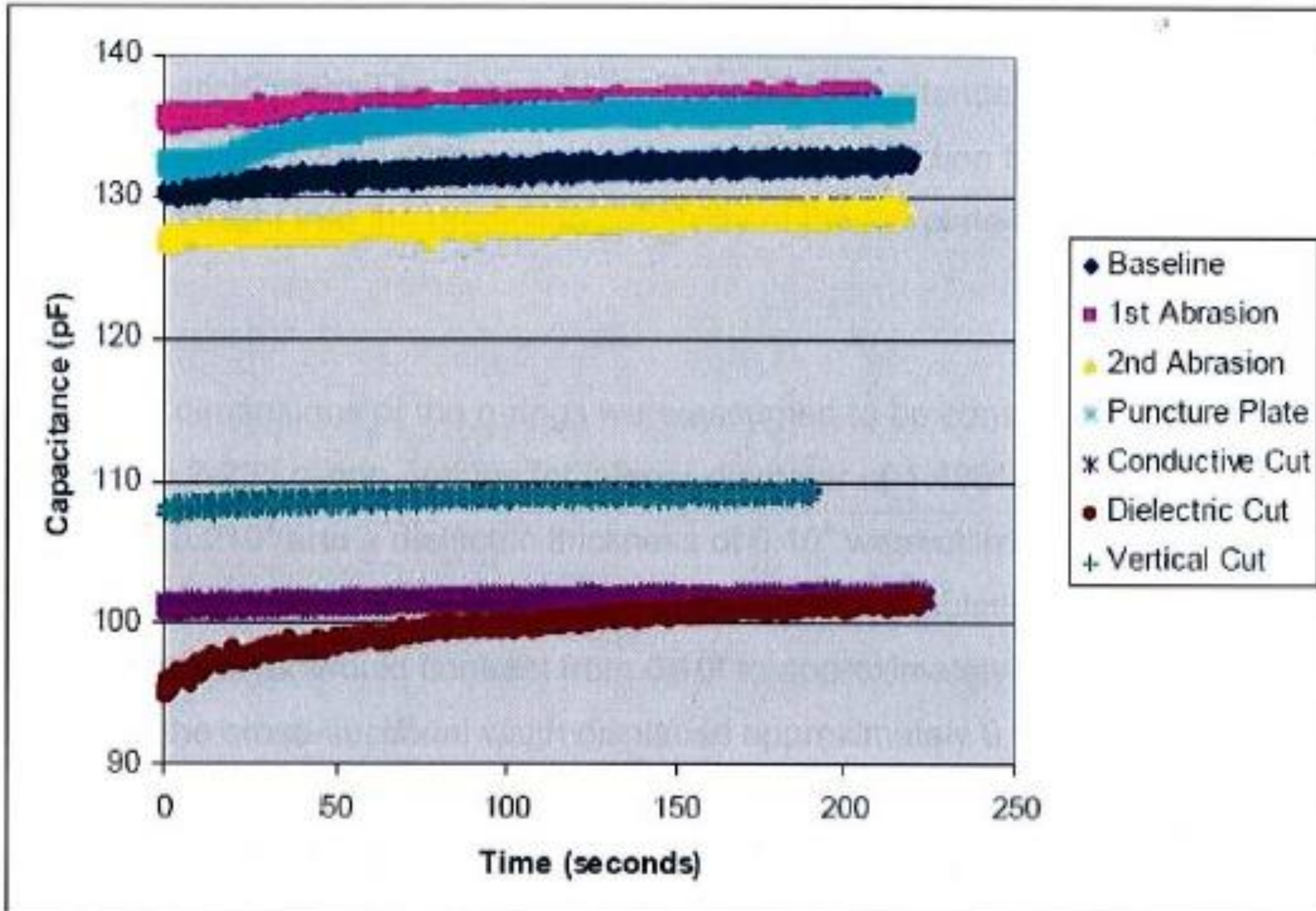
O-RING TESTING





- O-rings were tested in a compression test fixture.
- Capacitance increased with applied pressure.

O-RING SENSOR RESULTS



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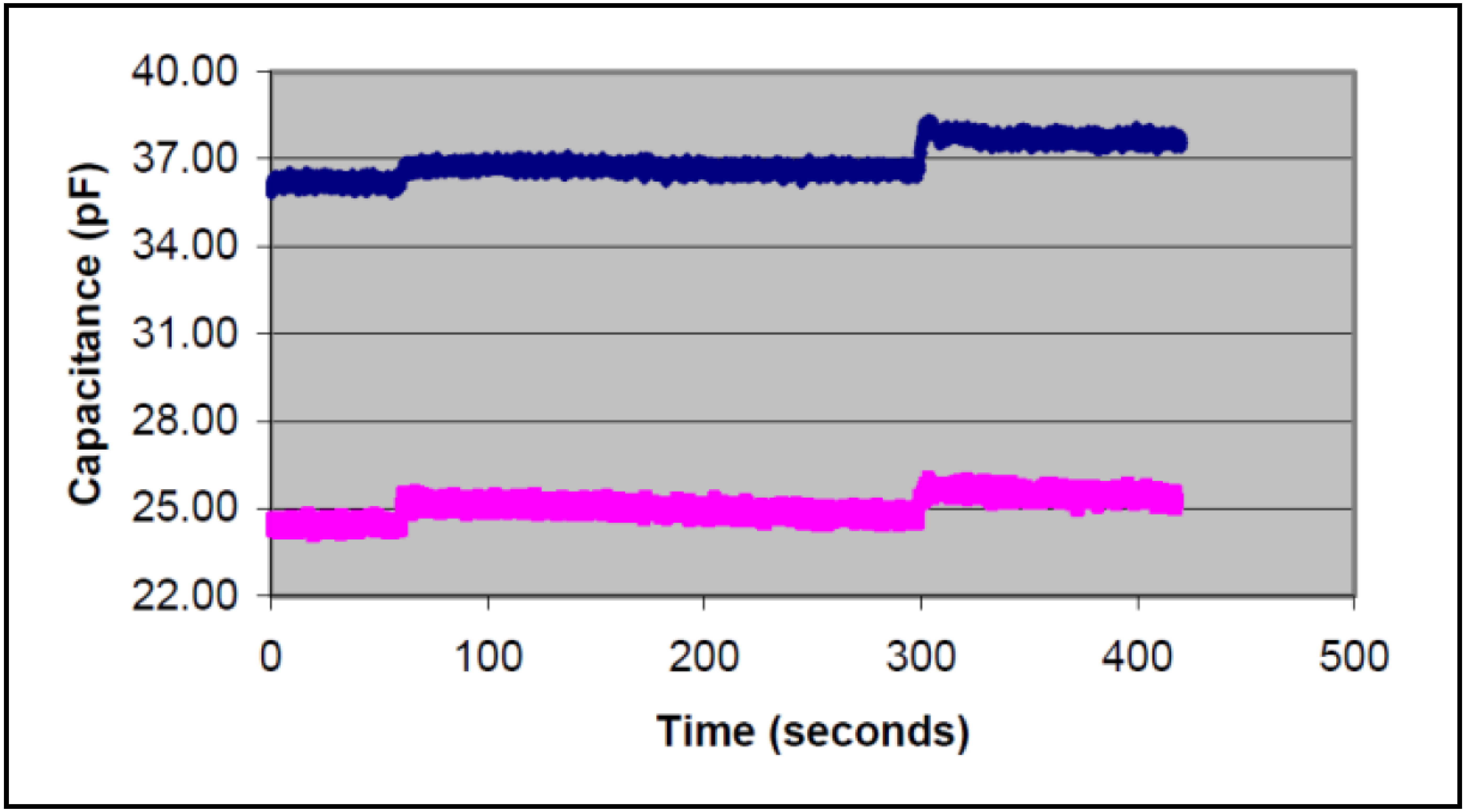
O-RING CHEMICAL FAILURE

- Initial capacitance was measured (pink)
- An incompatible chemical which induced swelling was added at 1 minute and 15 minutes and capacitance was measured (blue).



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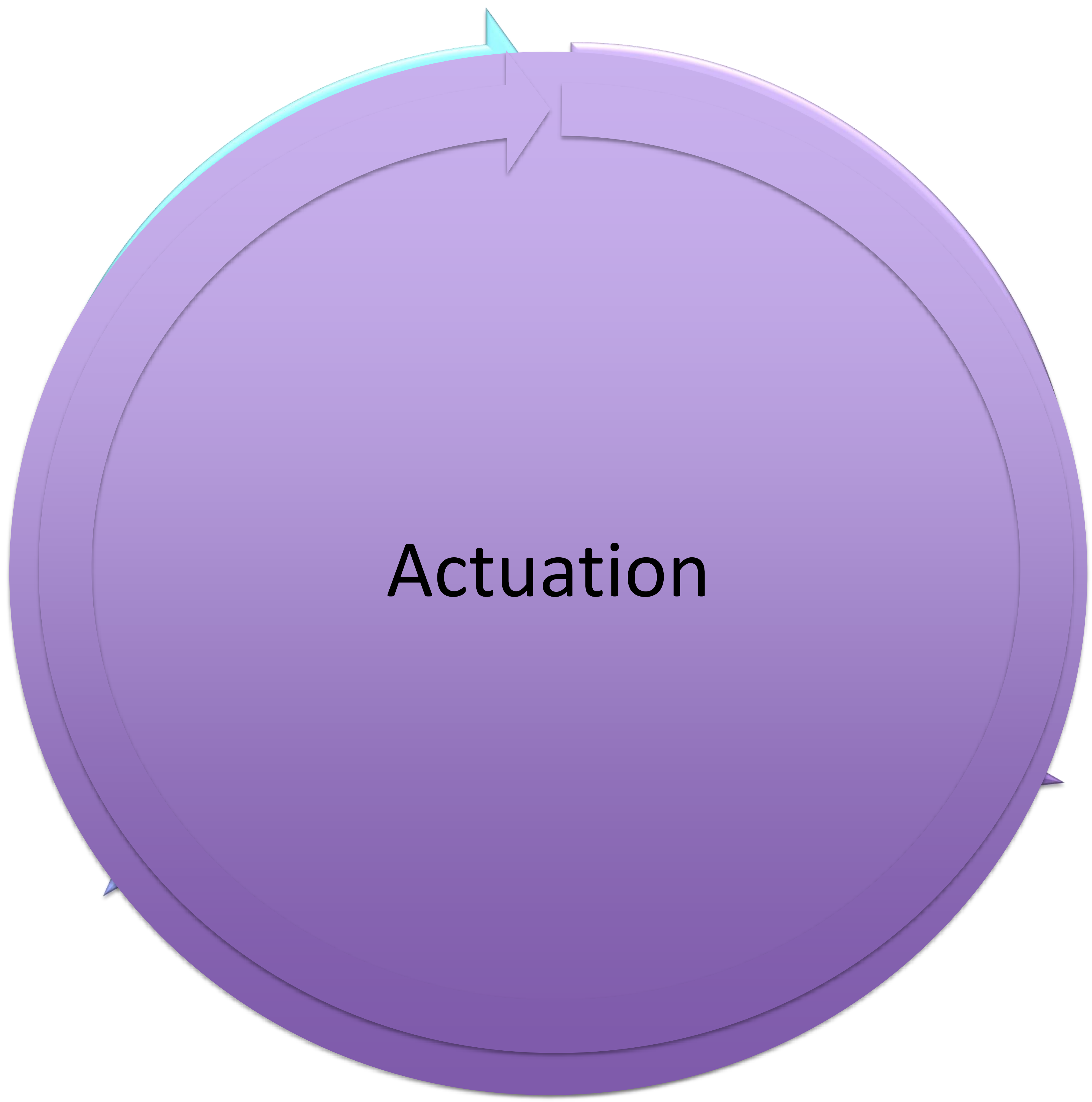
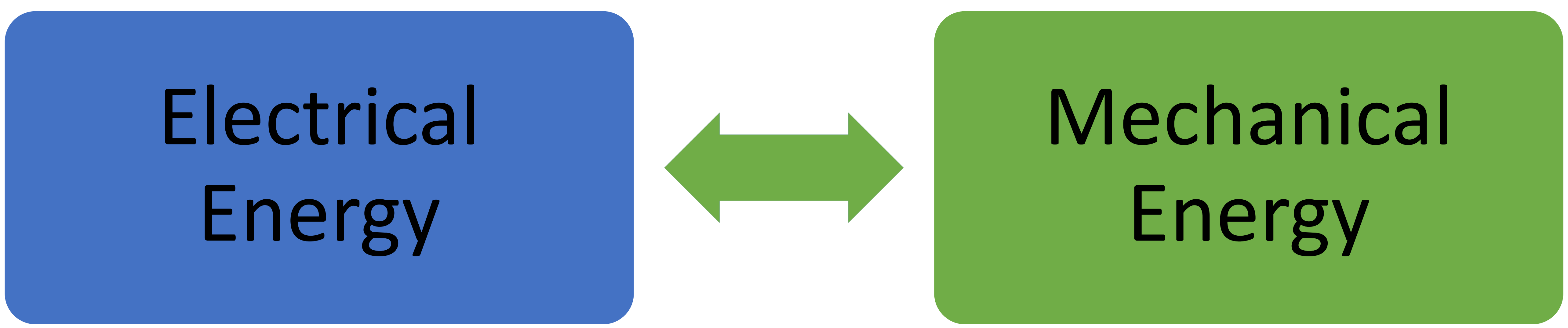
PROCESS FLOW



ELECTROACTIVE POLYMERS

Material that can convert between electrical energy and mechanical energy



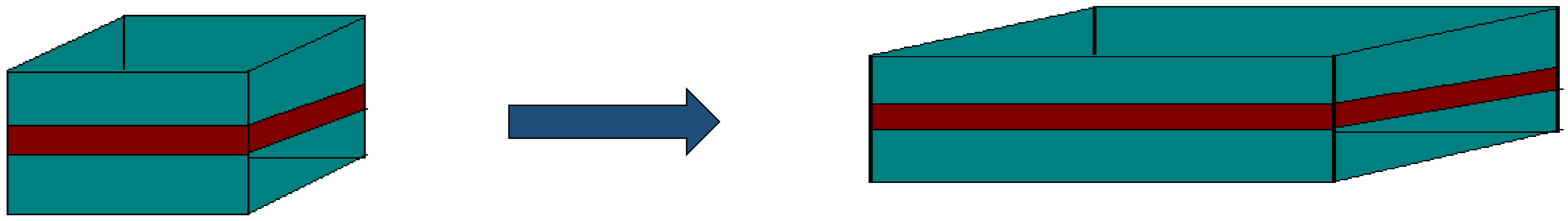
Two main categories of electroactive materials – ionic and electric

- Ionic – transfer ions or molecules in response to electrical energy
- Electric – Coulomb forces from the supply create electromagnetic fields. Due to the property of electrostriction, the material adjusts its structure to reach equilibrium with the field.

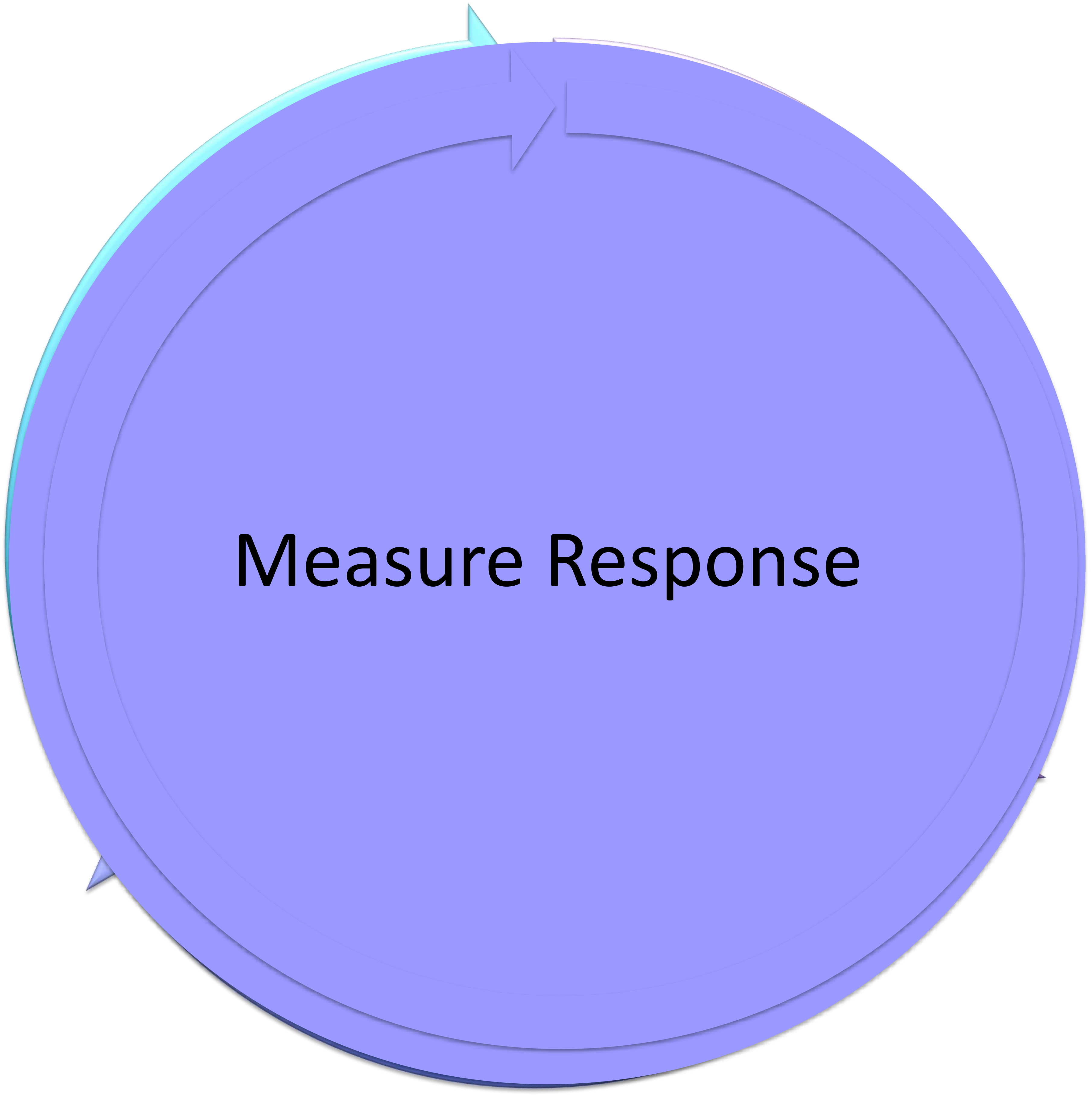
DIELECTRIC ELECTROACTIVEPOLYMERS… How they move

Coulombic Charge Interaction – As the capacitor charges a Maxwell stress is produced from changes in the electric field distribution within the dielectric as the material is strained.

Electrostriction – Material contains randomly aligned electrical domains. When an electric field is applied the domains become oppositely charged and attract reducing material thickness.

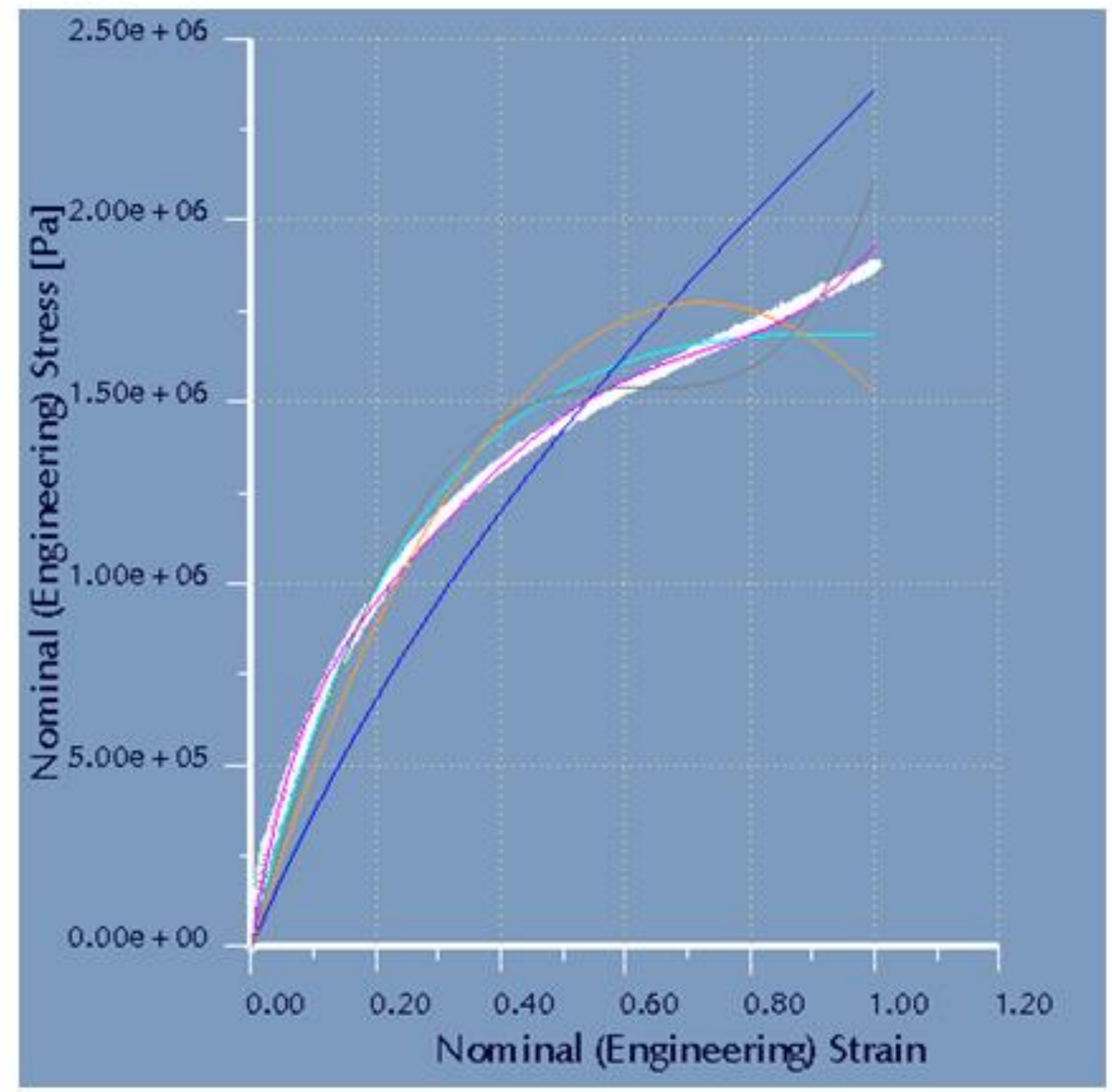


PROCESS FLOW



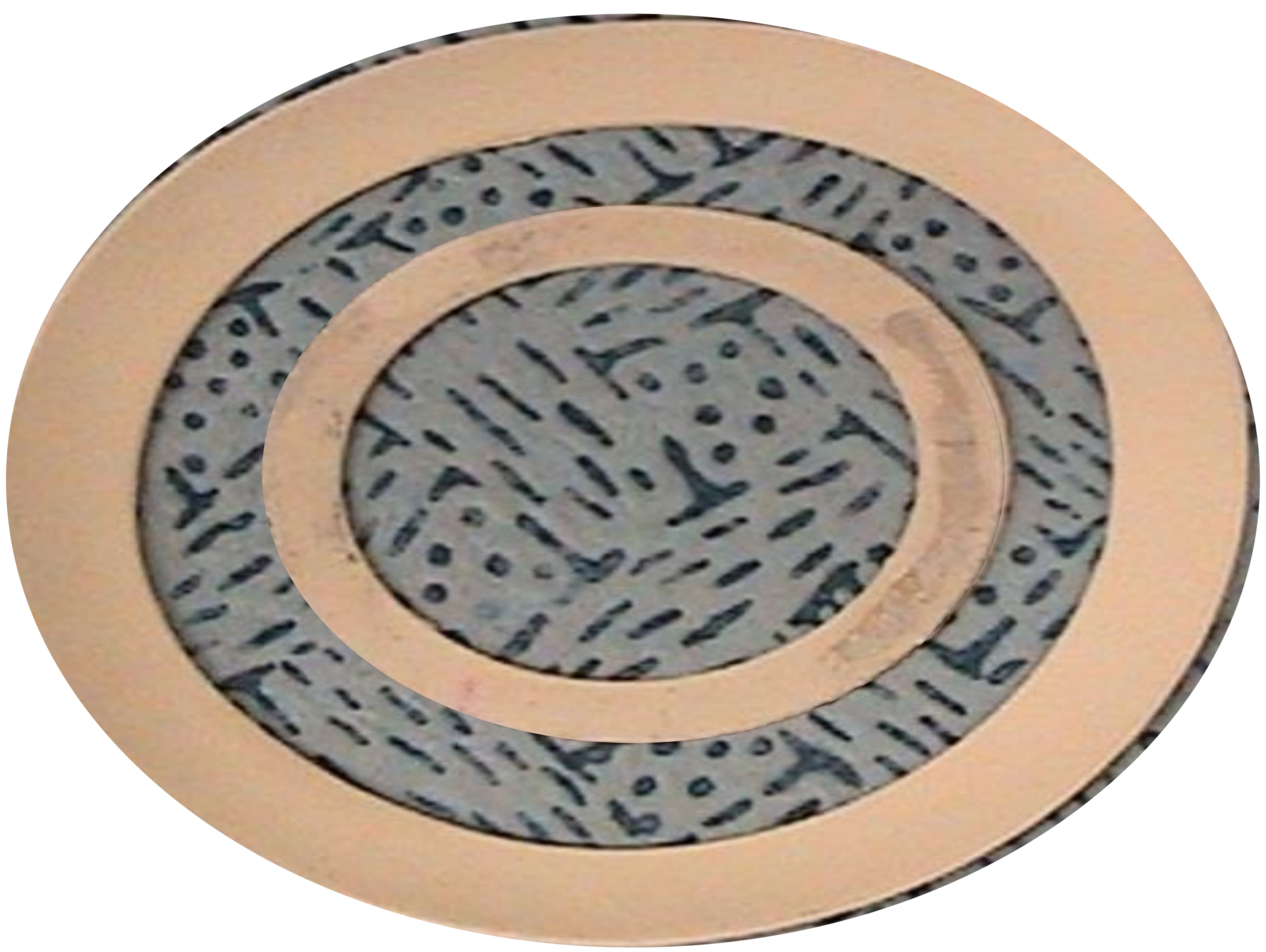
INDUSTRIAL MATERIALS

- Raw materials were based on polymers currently used in industrial devices
- Optimal Young’s modulus, tensile strength, temperature resistance, and chemical resistance found in current designs.
- Faster transition to market



Krutz, Gary and Newell, Brittany. “Electroactive actuators, systems equipped therewith, and methods of use and manufacture. January 25, 2013. Publication No. US 2015/0091254 A1

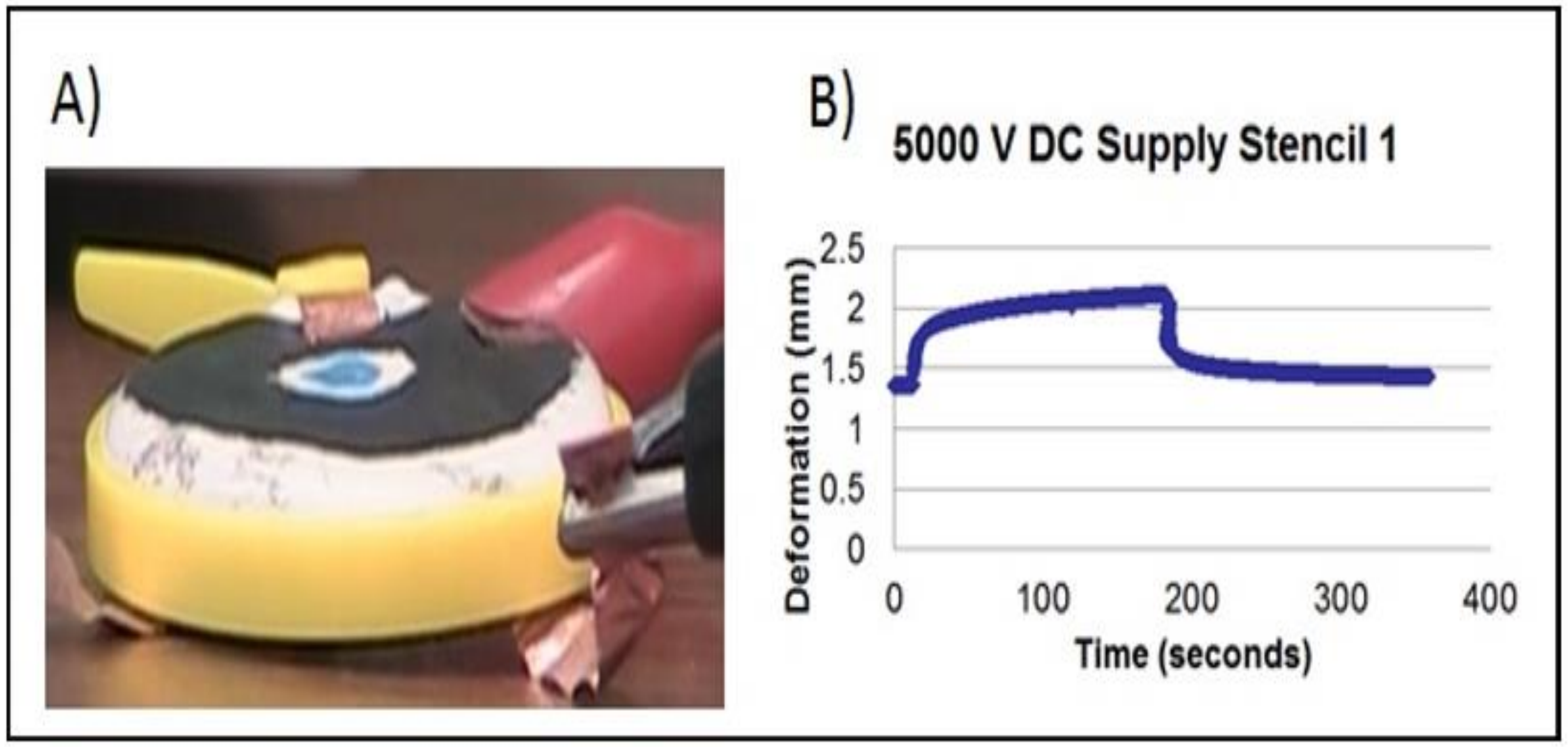
NOVEL PRE-STRAIN METHOD

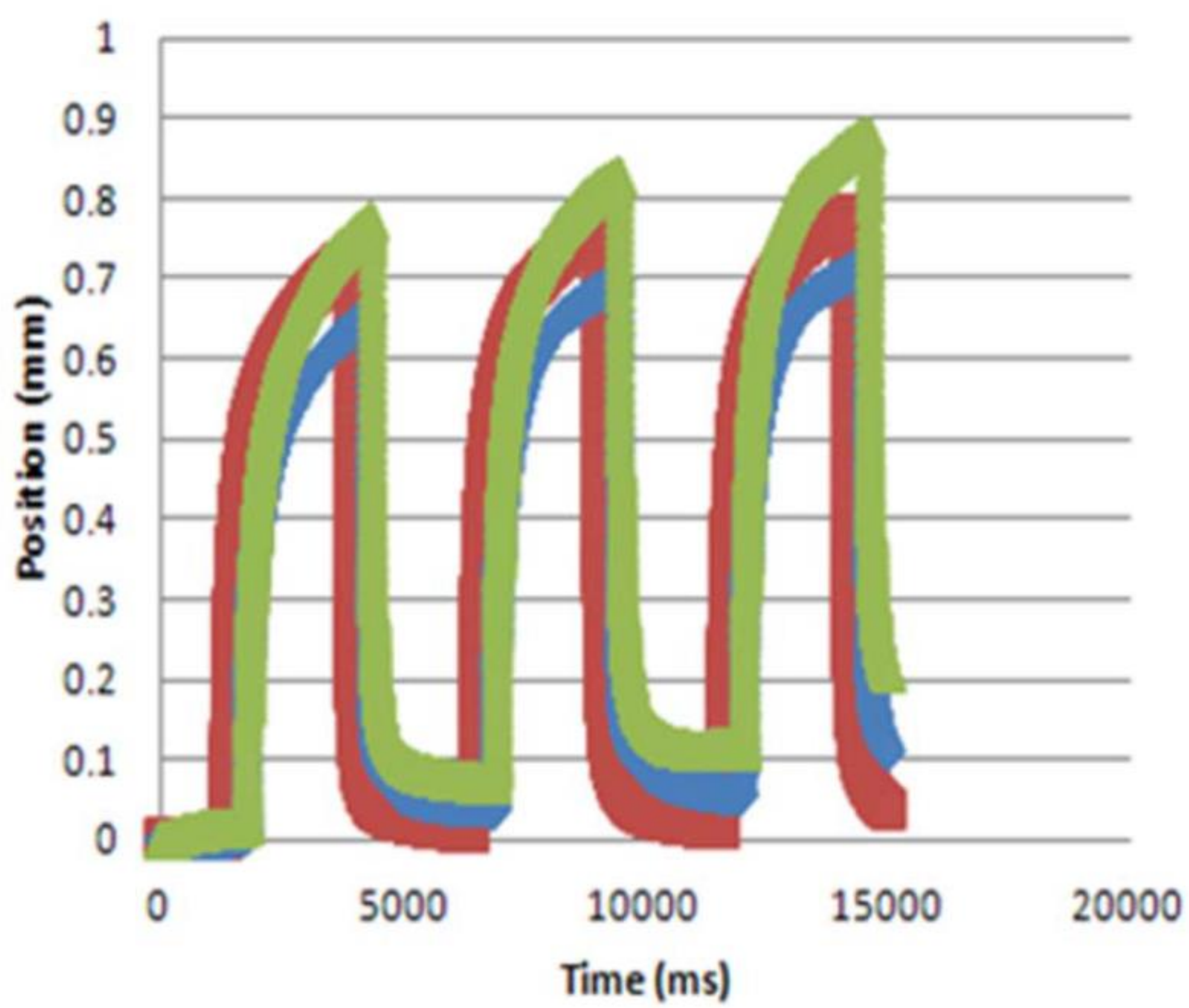


Krutz, Gary and Newell, Brittany. “Electroactive actuators, systems equipped therewith, and methods of use and manufacture. January 25, 2013. Publication No. US 2015/0091254 A1

- Previous research, Pelrine et al. 2000 stated that mechanical pre-strain increased the actuation potential of EAP materials by greater than 100%.
- Mechanical pre-strain is significantly more challenging for denser polymeric materials such as rubber and provides a challenge for scalability.
- Novel chemical pre-strain method was developed that can be administered in-line during the manufacturing process and is 97% reversible.

ELECTROACTIVE POLYMER RESULTS





DEVICE ACHIEVEMENTS

- Displacements of over 1 mm
- Force values for single layer designs of 0.97 N
- O-rings composed of the same polymer base, providing cohesive layers with comparable performance.

CONCLUSION

- Capablity to sense device health demonstrated for a variety of industrial components
- Actuation through electroactive polymer industrial materials demonstrated.
- Measured response capability shown through electroactive polymer construction