COMSOL CONFERENCE 2019 BOSTON

Smart Pipeline Structural Health Monitoring of Crack or Fracture Propagation Using Piezoelectric Sensor

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Motivation:

Economical and Human losses due to Pipeline failures

- Jan 10, 2018: Pipeline in Pearl City, Hawaii ruptured and leaked 500 gallons of fuel oil into residents' yards.
- Jan 14, 2018: Natural gas pipeline ruptured, leading to a fire in Geismar, Louisiana.
- Jan 31, 2018: Gas pipeline exploded & burned in Noble County, Ohio.
- Feb 18, 2018: a 16-inch crude oil pipeline ruptured in Oklahoma and 84,000 gallons of crude were spilled.
- Feb 23, 2018: House in Dallas, Texas exploded, killing a girl, and injuring 4 others in her family due to pipe gas leak.
- June 7, 2018: 36-inch natural gas transmission pipeline exploded and burned in West Virginia.

Literature Review

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Anomaly detection techniques

- Non-continuous methods: inspection by drones, smart pigging, or trained dogs [1]
- Continuous methods: fiber optic cable, acoustic sensor, or video monitoring [2]

❖ Limitations:

- Sensors accuracy, high false alarm redundancy
- Very high installation, operation and maintenance costs [3]

✓ What’s needed:

- Cheap implementation solution, minimal power consumption
- Continuous data collection & anomaly detection (type + location)

Objectives

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1. Detect an anomaly in a pipeline such as a deformation caused by a crack or fracture using a piezoelectric sensor.

2. Find a relationship between the magnitude of the deformation of the pipe in the xy, xz, and yz directions and the magnitude of the voltage across the piezoelectric patch.

3. Find a relationship between the deformation propagation and the rate of voltage increase.

4. Detect the anomaly location.

Simulation Analysis

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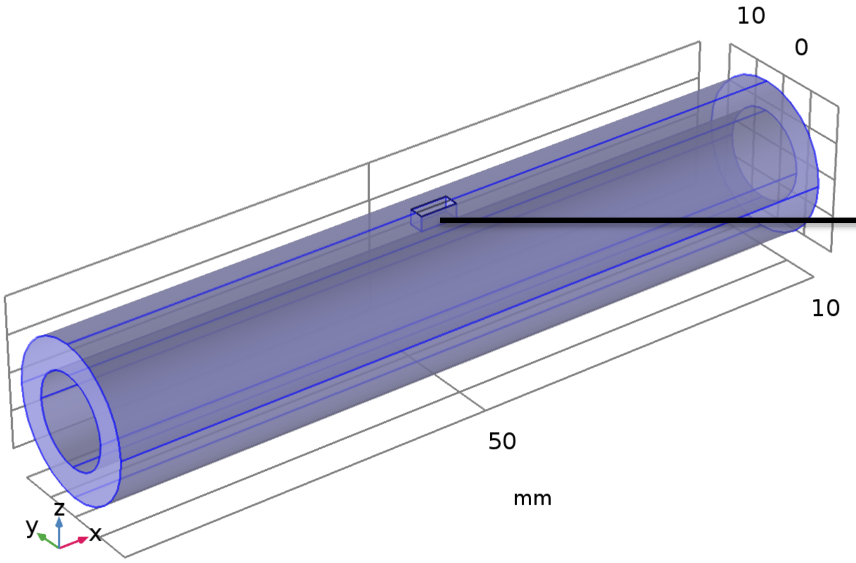
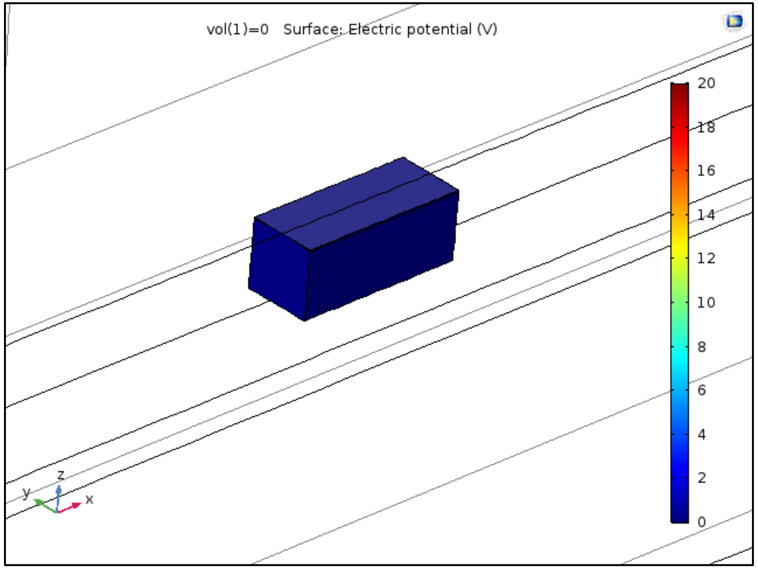


3D Model of the pipeline



PZT with a 20V charge across its ends
→ Induce anomaly

Results

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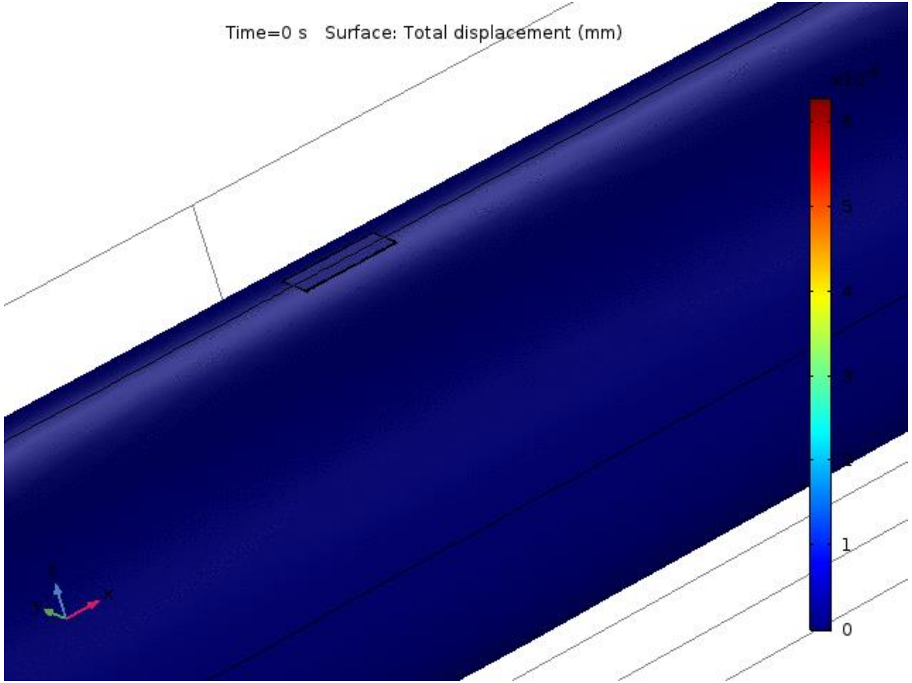
The anomalies are in a form of deformations caused by changing the voltage across the piezoelectric material.



Pipe deformation when 20 V is induced across the PZT patch

Results

YZ plane

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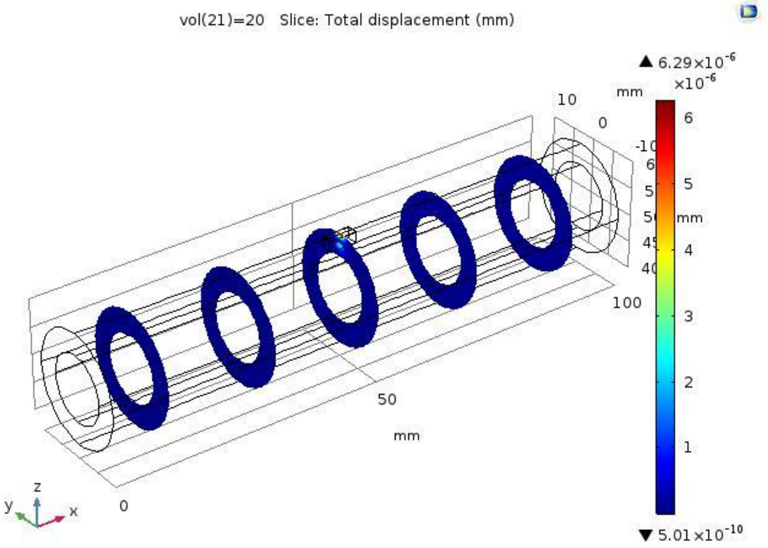
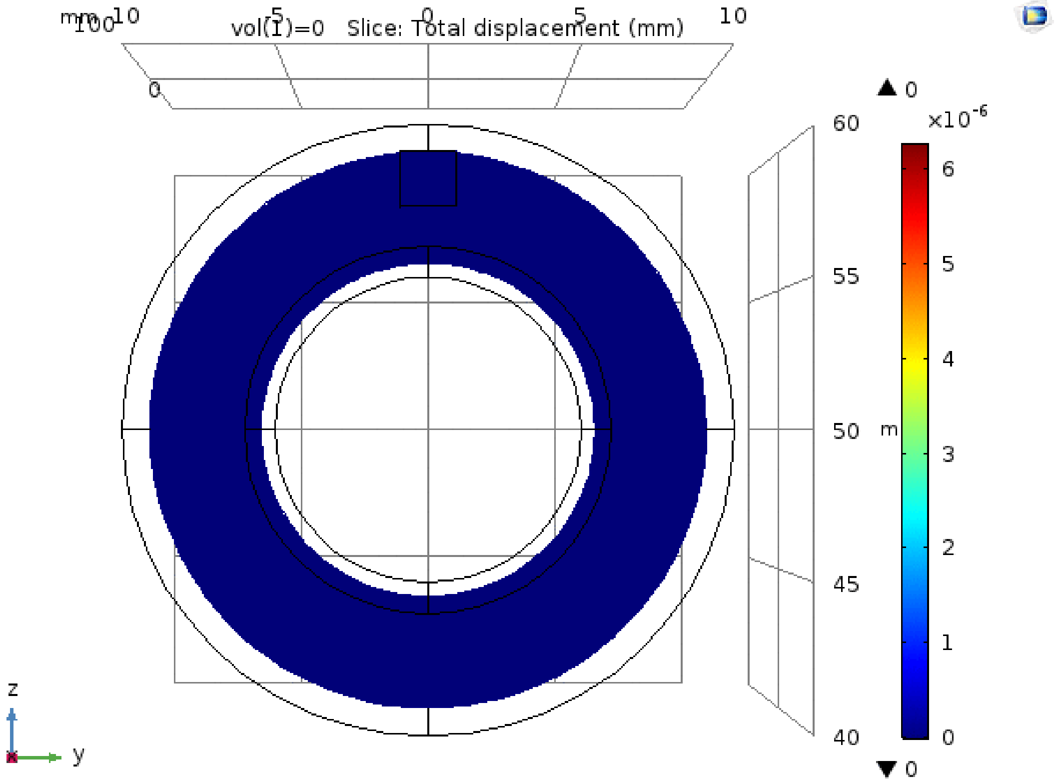
The purpose of the simulation results analysis is to find a correlation between the deformations in the pipe and the electric potential across the PZT patch.



YZ cross sections of total displacement along the pipeline when 20 V is induced across the PZT patch

Results

YZ plane

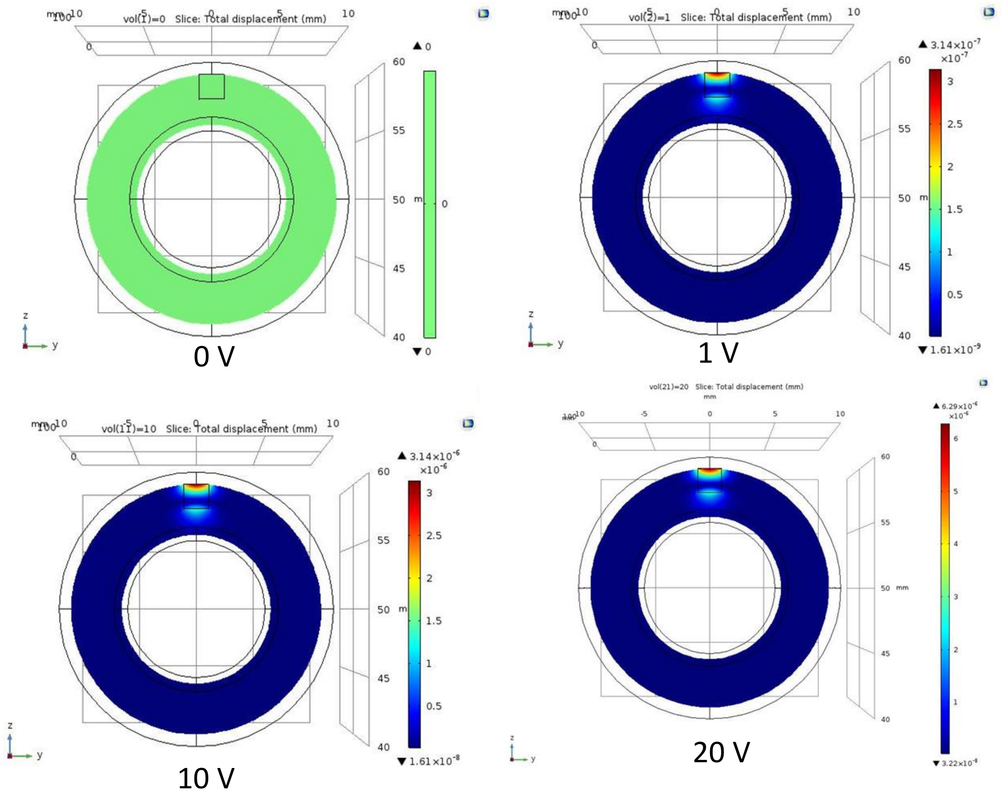


YZ Pipe deformation with an increasing electric potential across PZT patch

→ linear relationship between the maximum deformation observed at the pipe and the voltage induced through the PZT patch.

Results

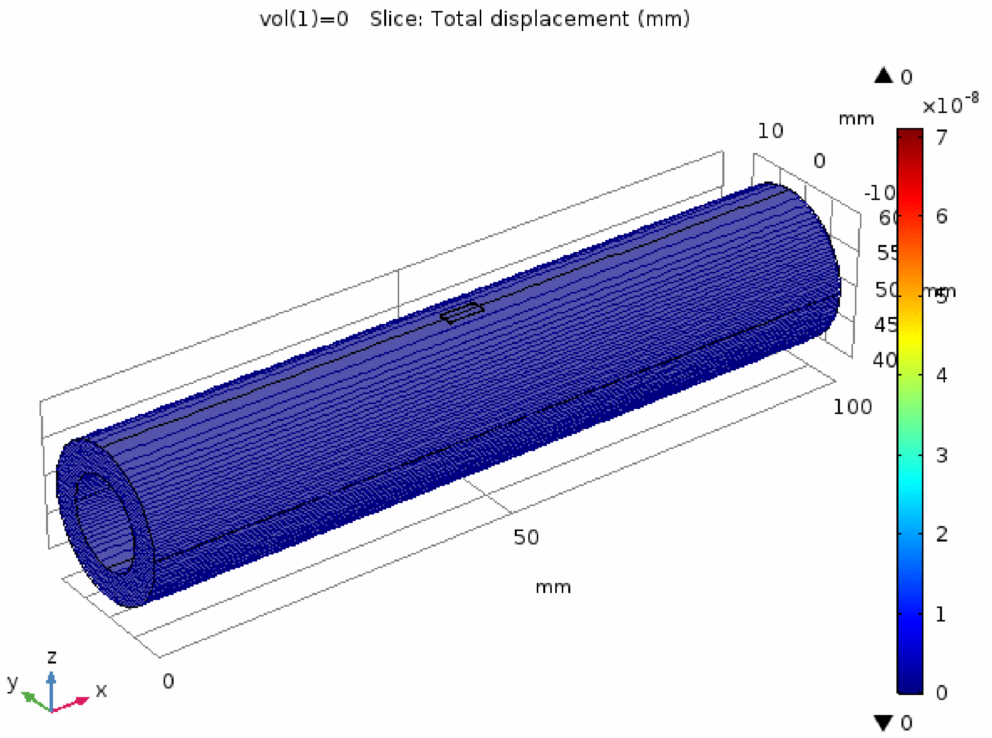
YZ plane



Linear relationship between Pipe deformation and Electric potential

Results

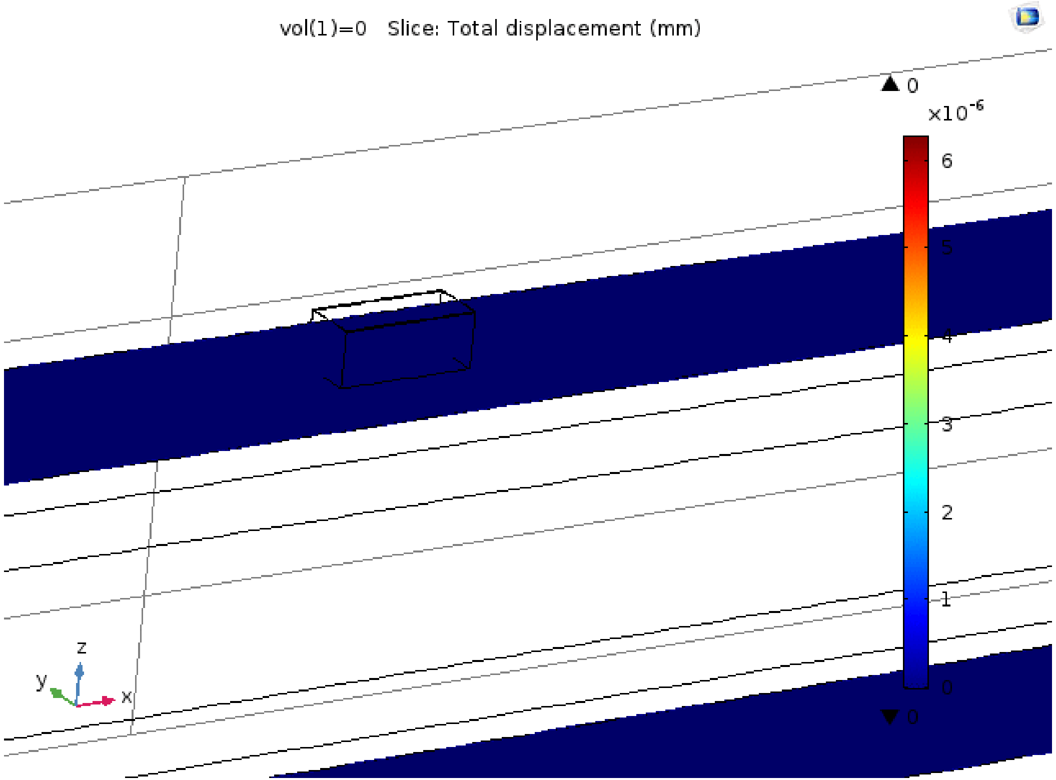
XY plane



XY Pipe deformation with an increasing electric potential across PZT patch

Results

XZ plane



XZ Pipe deformation with an increasing electric potential across PZT patch

Results

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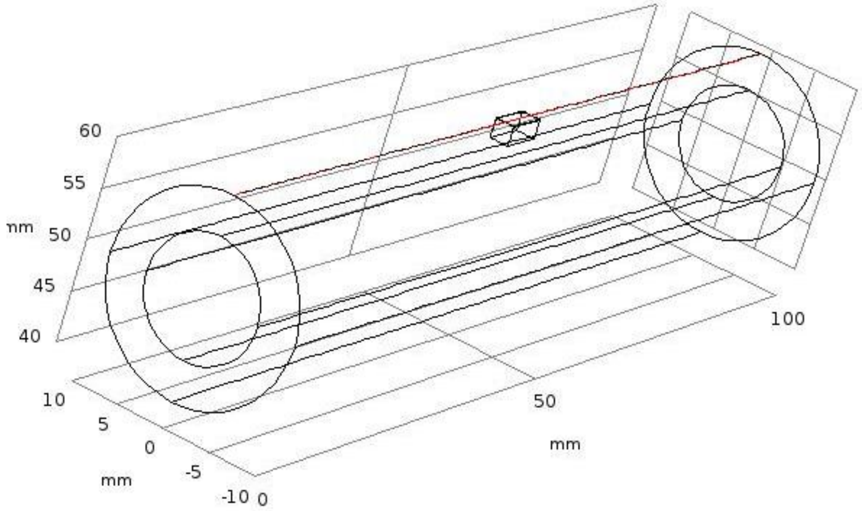
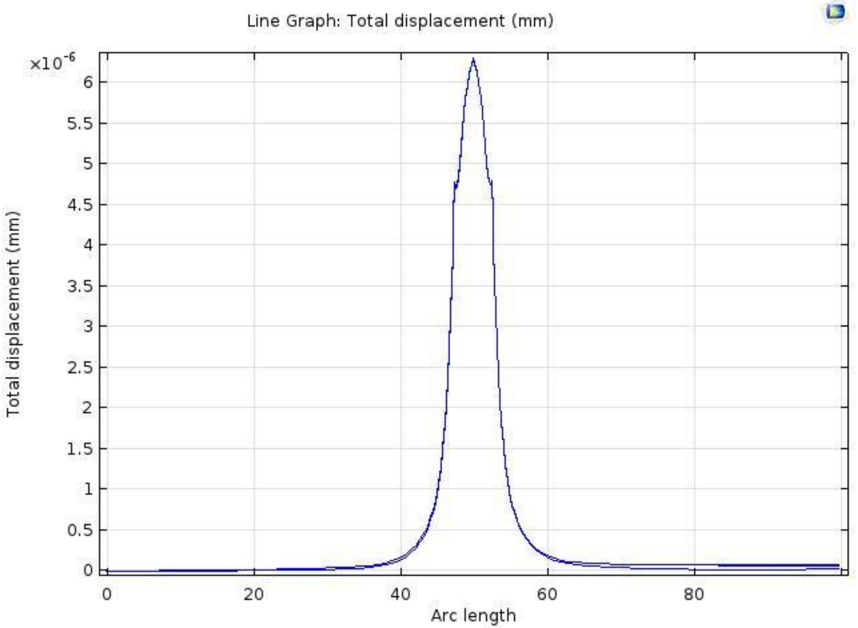


Line along which data are collected to plot XZ deformations



Plot of XZ deformations when 20 V is induced across the PZT patch

Conclusion

Anomaly detection using piezoelectric sensors is possible

- A crack was simulated across the surface of the pipe.
- Linear relationships between the voltage across the PZT patch and the deformations.
- Linear relationships between the rate of voltage increase and the deformation propagation.
- Results can act as baseline measurement to enhance structural health monitoring of the pipeline by detecting the horizontal location of anomalies with a better precision.

Future work

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- Combine the results found in this paper with machine learning or statistical analysis

→ Generate an algorithm to detect anomalies, their type and location

- Add another piezoelectric sensor & induce high frequency waves between sensors

→ Detect anomalies with higher precision

References

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[4] G. Park, H. H. Cudney, and D. J. Inman, "Feasibility of using impedance-based damage assessment for pipeline structures," *Earthq. Eng. Struct. Dyn.*, vol. 30, no. 10, pp. 1463–1474, Oct. 2001.

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[6] X. P. Qing *et al.*, "Development of a real-time active pipeline integrity detection system," *Smart Mater. Struct.*, vol. 18, no. 11, p. 115010, Nov. 2009.

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Thank You

Any Questions?

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