A Novel Capacitive Sensing Method with Differential Excitations for Hydrogen Pipeline Inspection

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Objective

- Pipeline transportation is an economical and efficient transportation approach.
- Hydrogen atoms may diffuse into metal, leads to Hydrogen induced cracking (HIC).[2]
- A reliable NDT method is needed for HIC detection.

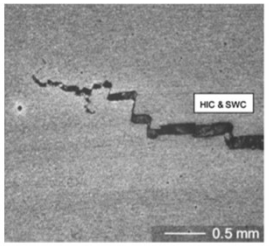

Fig.1. The image of a hydrogen induced cracking[1]

Challenges

- Small dimension of HIC
- Curved surface inspection
- Inspection speed

Strategies

- Differential capacitive sensing
- Flexible sensor
- Sensor array

Differential capacitive sensing

- High sensitivity for conductive material.
- Wide working frequency band.
- Differential capacitive sensor can suppress unwanted signal
  - ➢ Background signal.
  - ➢ Lift-off noise.

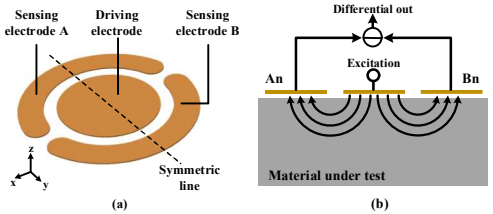

Fig.2. (a) Structure of differential capacitive sensors. (b) Schematic illustration of the principle of differential capacitive sensing method

Simulation

- Defect:10mm×3mm × 3mm;
- Lift-off: From 0.5mm to 1mm

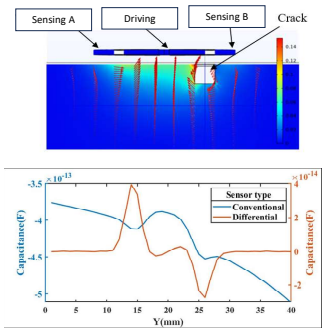

Fig.3. The image of a 3D COMSOL capacitive sensing model and the simulation result for conventional capacitive sensor and proposed sensor.

Experiment

- Frequency: 50kHz ; Scanning step size: 1mm

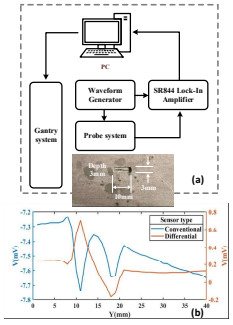

Fig.4. (a) The scanning experiment system. (b) The line scan result of differential and conventional methods

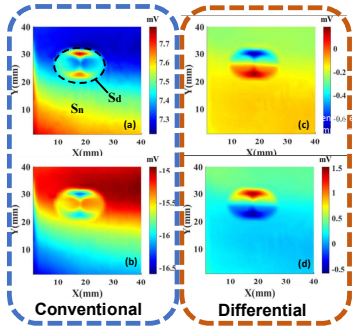

Fig.5. Imaging results of quadrature and in phase components from the conventional sensor (a), (b) and differential sensor (c), (d)

Flexible sensor array

- Reduce lift-off to acquire stronger signal.
- Improve inspection efficiency by covering larger area
- An instrument amplifier is utilized as a subtractor
- Gain: 20; Bandwidth: 10.2kHz-1.5MHz.

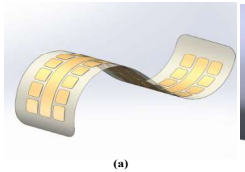

Fig.6. (a) The structure of proposed flexible differential capacitive sensors array. (b) Image showing the probe scan inside the pipe .

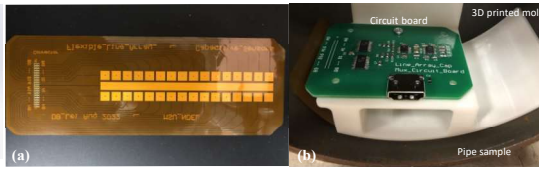

Fig.7. Images of flexible sensor array(a) and integrated prototype probe(b).

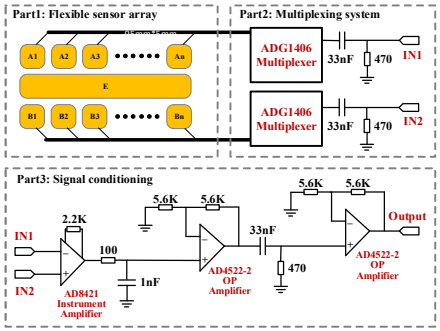

Fig.8. The schematic of the array probe system: part1: array probe, part2: multiplexing system, part3: signal conditioning circuit.

- 10mm×1mm×1mm
- #1: 0° #2: 30° #3: 60°

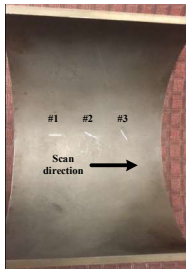

Fig.9. Image of pipeline sample with 3 artificial defects.

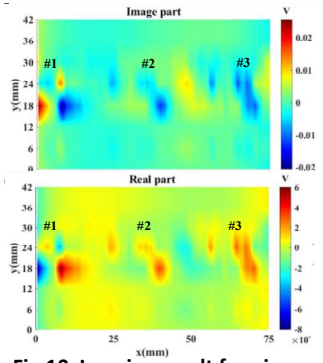

Fig.10. Imaging result for pipe sample with the prototype probe.

- Simulation results indicate that the method effectively suppresses the influence of lift-off.
- Experimental results show that the proposed method achieves an image with a higher signal-to-noise ratio (SNR) A flexible sensor array probe is designed and fabricated for inspecting curved surfaces.
- An image processing method based on this sensing method will be developed to aid in analyzing the size information of the defects.
- An inspection robot can be utilized to deploy the array probe system for in-line inspection.

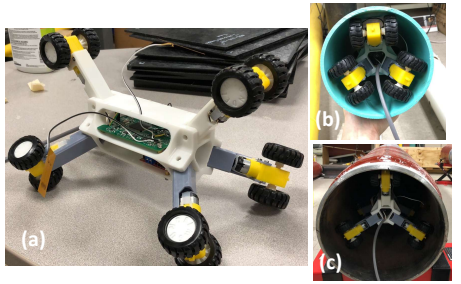

Fig.11. (a) The proposed in-line inspection robot with a flexible sensor and the images showing the robot inside the pipe with 6 inch (b) and 10 inch (c).

Acknowledgments

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https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=953

[1] Detection of Hydrogen induced Cracks During In-service inspection of Piping Using Ultrasonic Phased Arrays – Assessment of Fitness for Service Vol.20 No.6 (June 2015) -The e-Journal of Nondestructive Testing - ISSN 1435-4934

[2] S. Zhang et al., "The significant effect of tantalum on the hydrogen-induced cracking of pipeline steel: Morphology, hydrogen permeation, and theoretical studies," Corrosion Science, vol. 200, p. 110213, May 2022, doi: 10.1016/j.corsci.2022.110213.