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ACTIVE SENSING OF FATIGUE DAMAGE USING EMBEDDED ULTRASONICS

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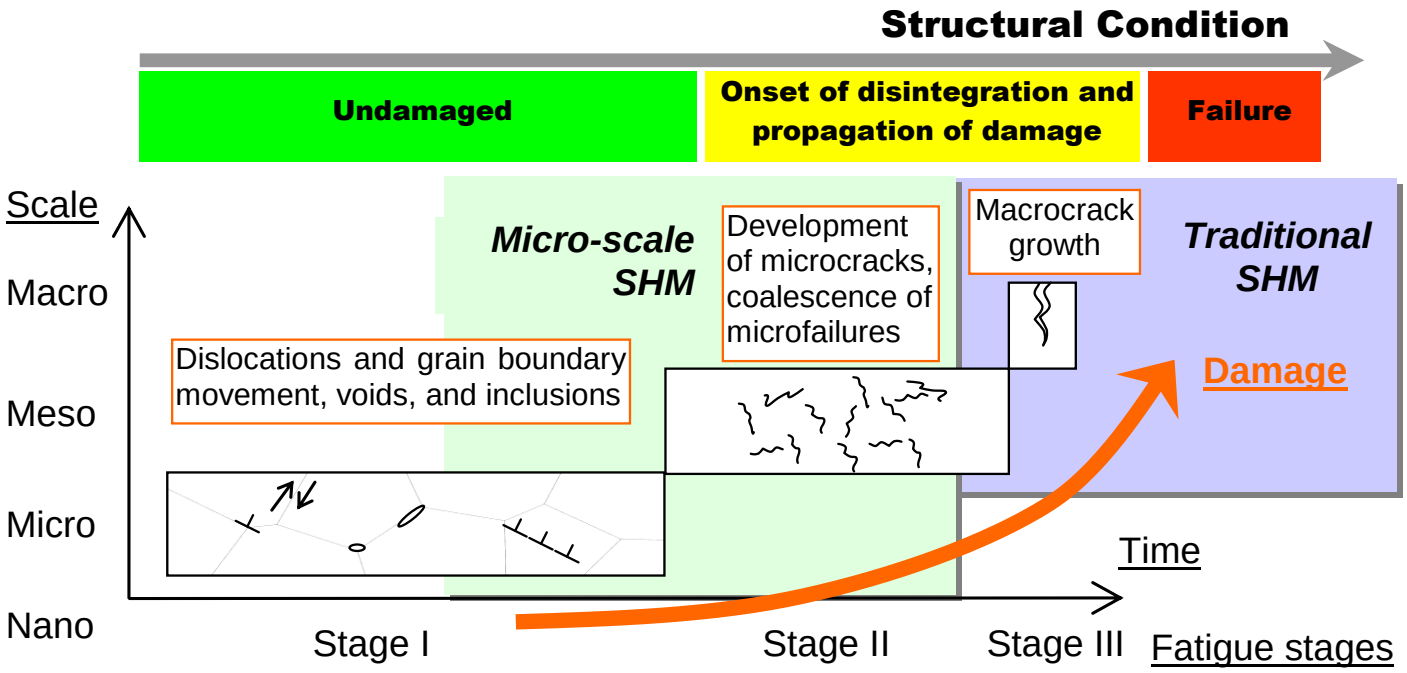
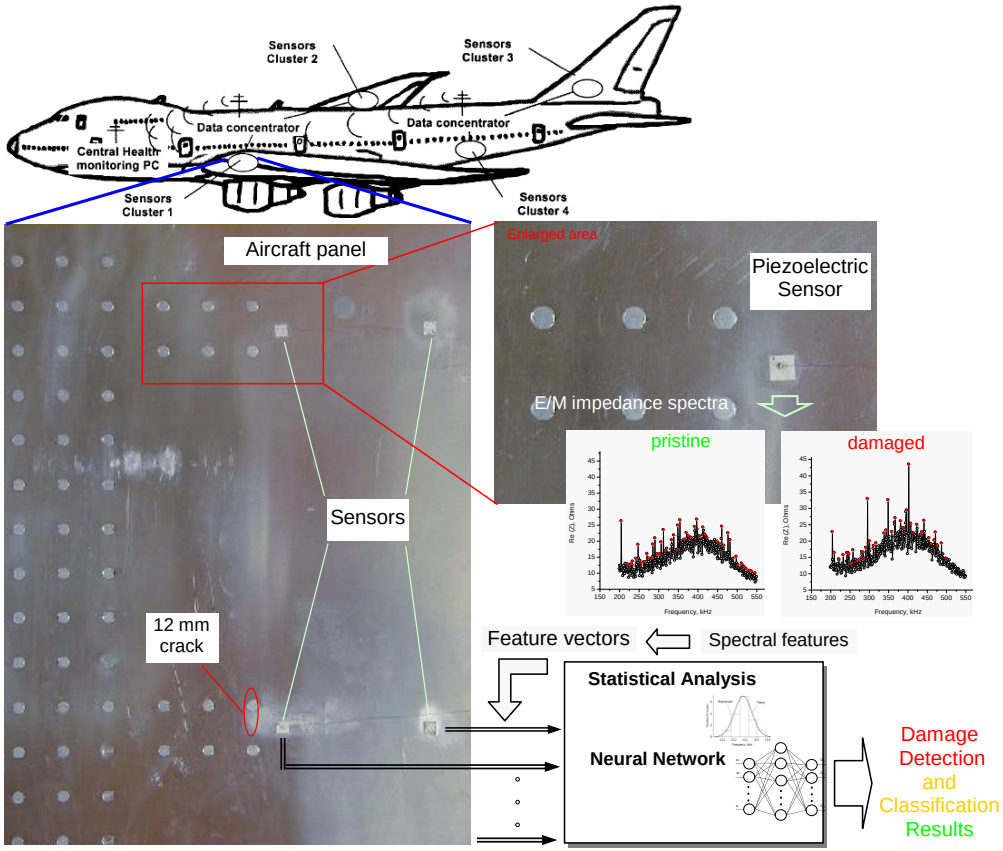
Micro-Scale Damage Detection

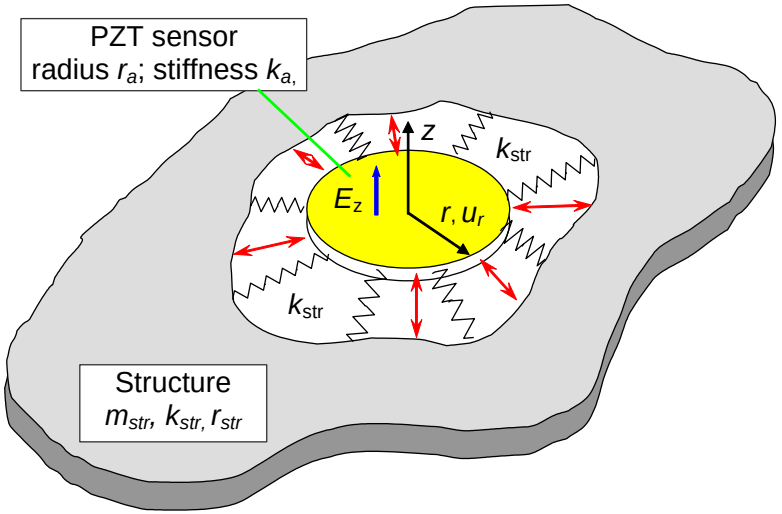


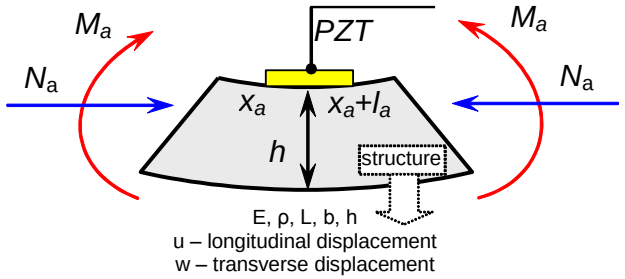
- Goal: Detect and quantify material/structural deterioration at the earliest stage possible. Potentially, before onset of cracking and macro-scale fracture.
- Micro-scale SHM Techniques
  - Acoustic Emission (passive technology)
  - Eddy Current (very local, need scanning)
  - Electro-mechanical impedance method
  - Nonlinear embedded ultrasonics

Principles of E/M Impedance Method

NEW MEXICO TECH







- Under electrical excitation, the bonded piezoelectric active sensor produces local strain parallel to the structural surface. The reaction of the host structure to this excitation can be presented in terms of dynamic structural stiffness or impedance

- Due to the mechanical coupling between the sensor and the host structure, the structural stiffness affects the sensor and, through electromechanical coupling inside the active element, is reflected in the electrical impedance measured at the sensor's terminals.

Electro-Mechanical Impedance Testing

Structural dynamics stiffness:
Can be linear or nonlinear

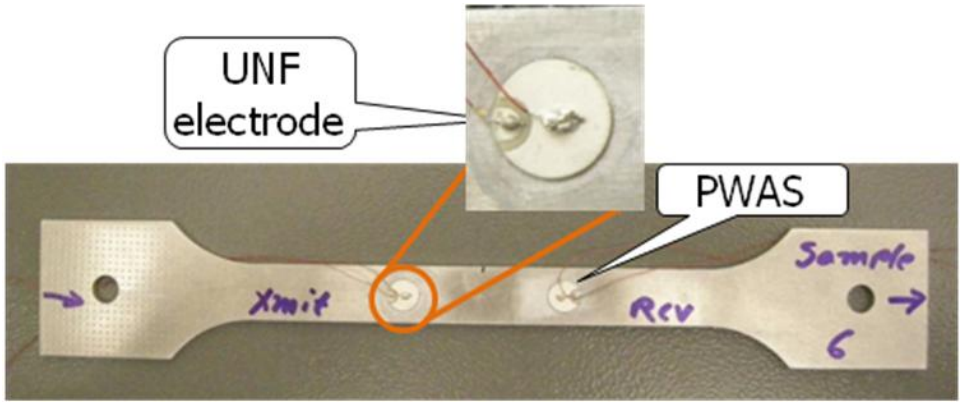
$$Y(\omega) = \frac{I(\omega)}{V(\omega)} = i\omega \cdot C\left(1 - \kappa_{31}^2\left(1 - \frac{1}{\varphi \cot \varphi + r(\omega)}\right)\right) \qquad r(\omega) = \frac{k_{str}(\omega)}{k_{PWAS}^b}$$

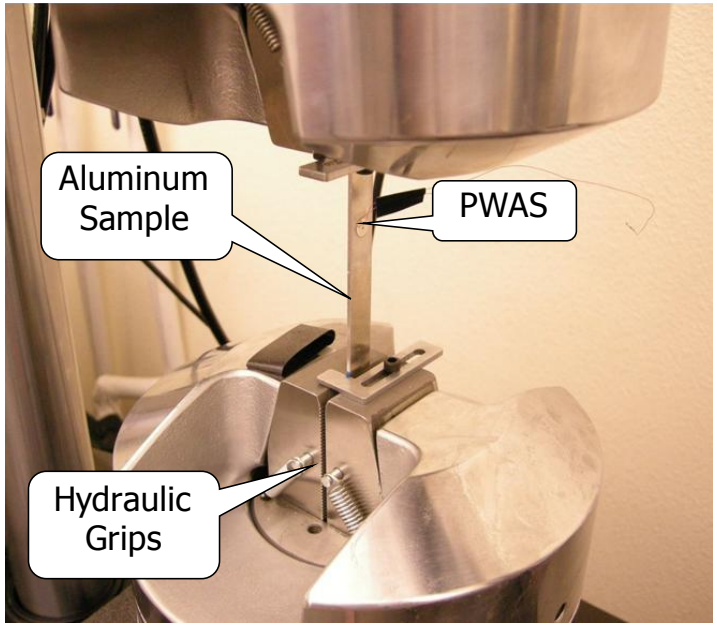
Admittance | Sensor dynamics | Structural dynamics

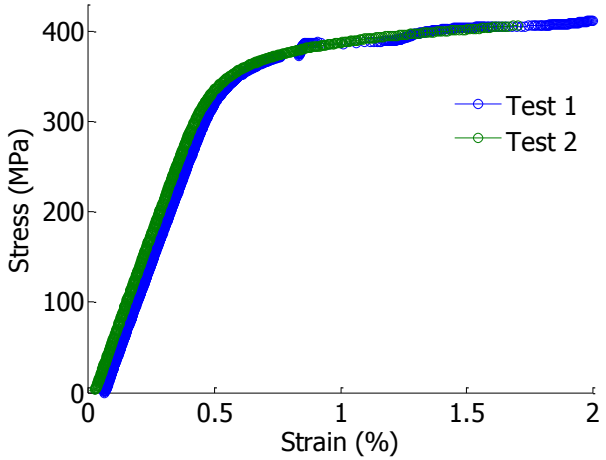
- Linear and nonlinear damage effects are reflected in the structural dynamic stiffness ratio.
- Structural dynamic characteristics can be obtained through electro-mechanical impedance measurements
- Fatigue damage modifies structural stiffness and thus impedance

Fatigue Samples

- 2024-T3 Aluminum Dog Bone with Rectangular Notch Stress Concentration
- ASTM standard 557M
- Piezoelectric-Wafer Active Sensors (PWAS) with UNF Electrode
- PWAS Permanently Bonded at Approx. 15 -20 mm from Stress Concentration

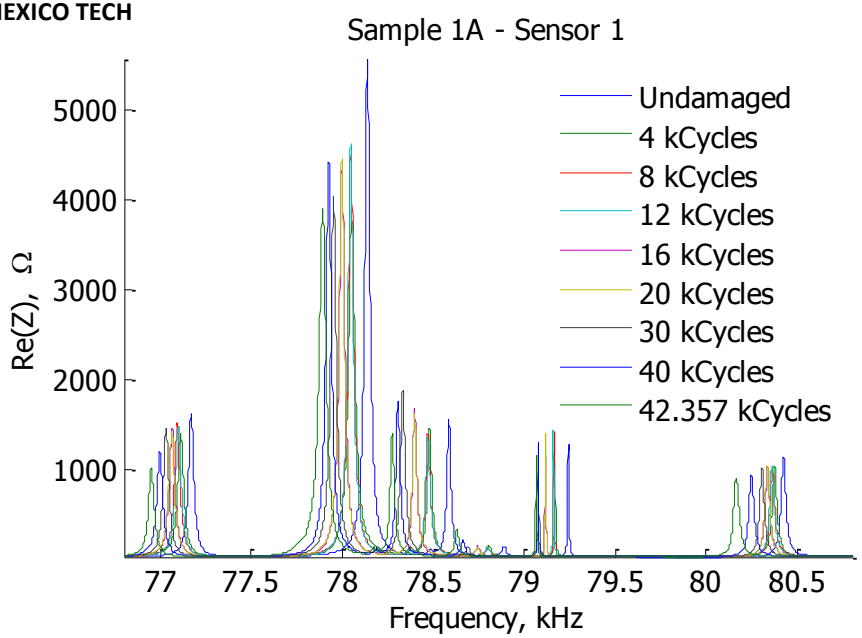


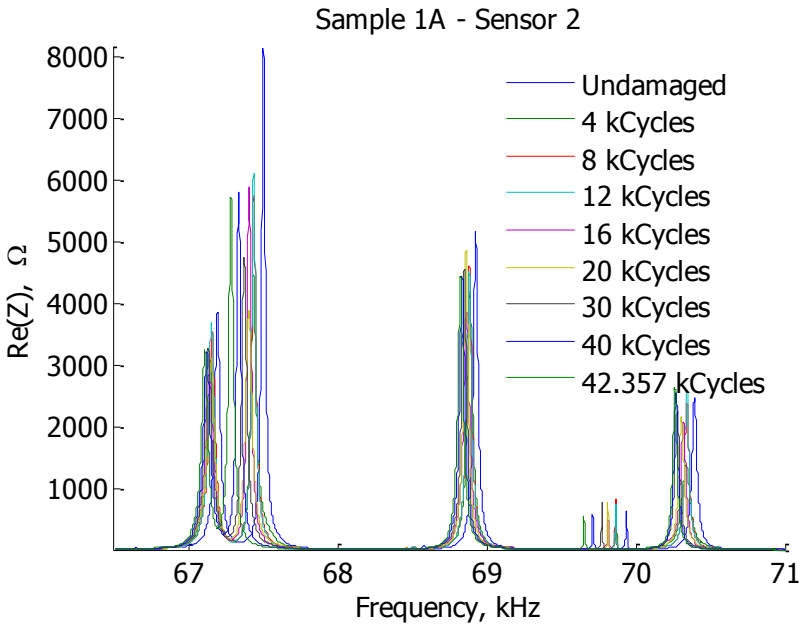


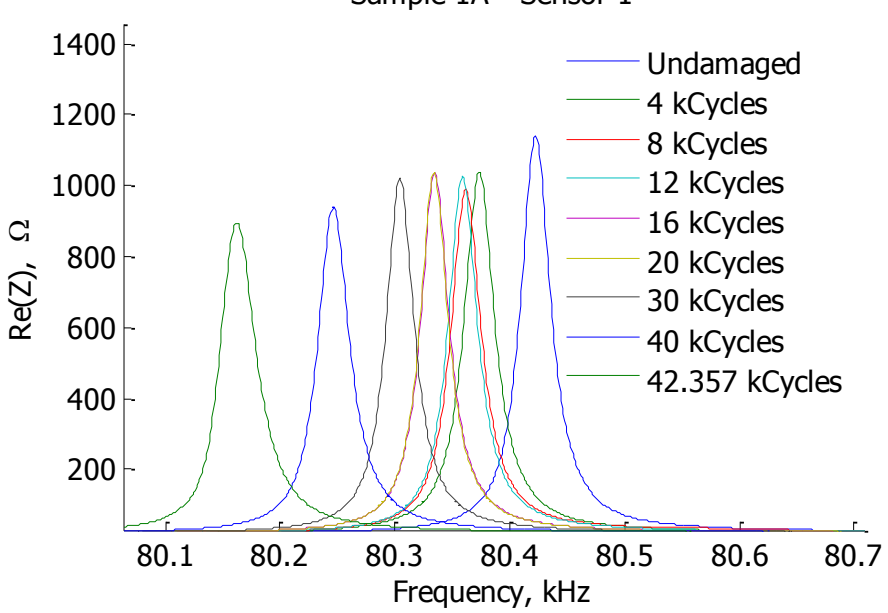


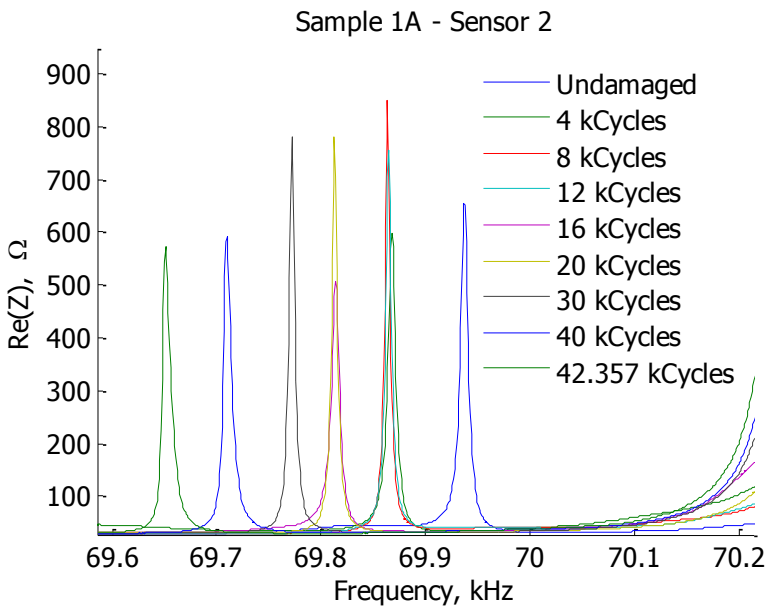
- MTS Dynamic Tester (370.10 Load Frame)
- Force-Controlled
- Harmonic actuation

Sample 1A Results

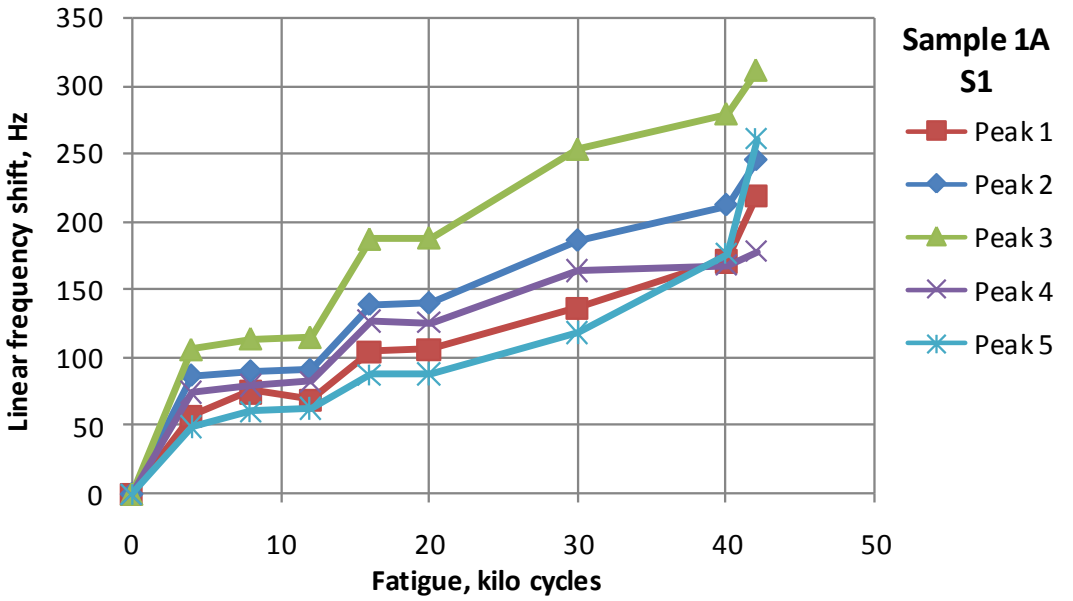


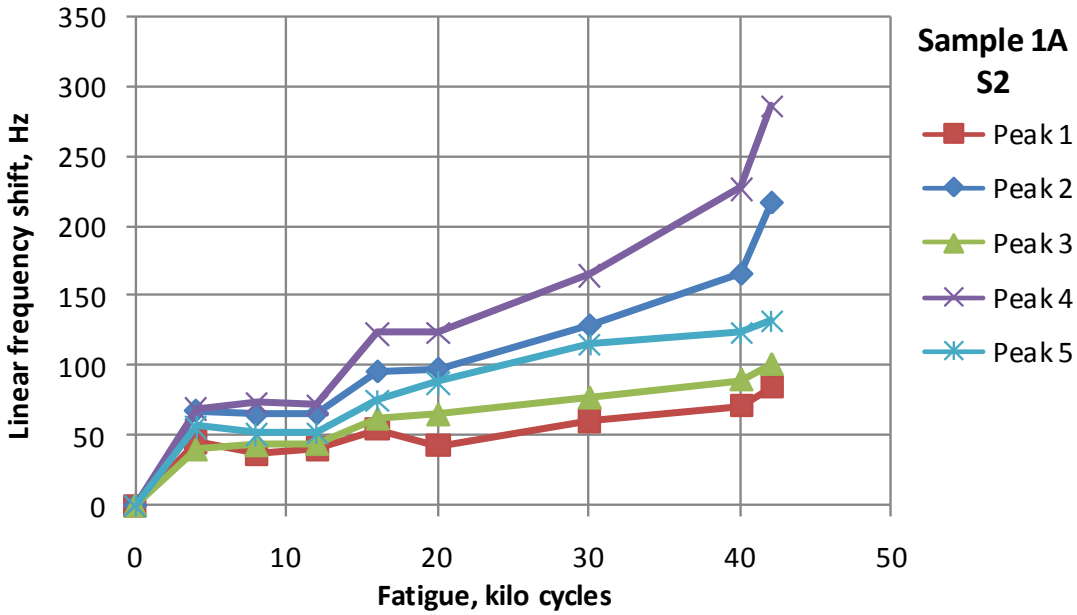






ELECTROMECHANICAL IMPEDANCE – SAMPLE 1





Nonlinear Resonance

Guyer and Johnson, Physics Today, 1999

Sound speed

Effect of hysteresis

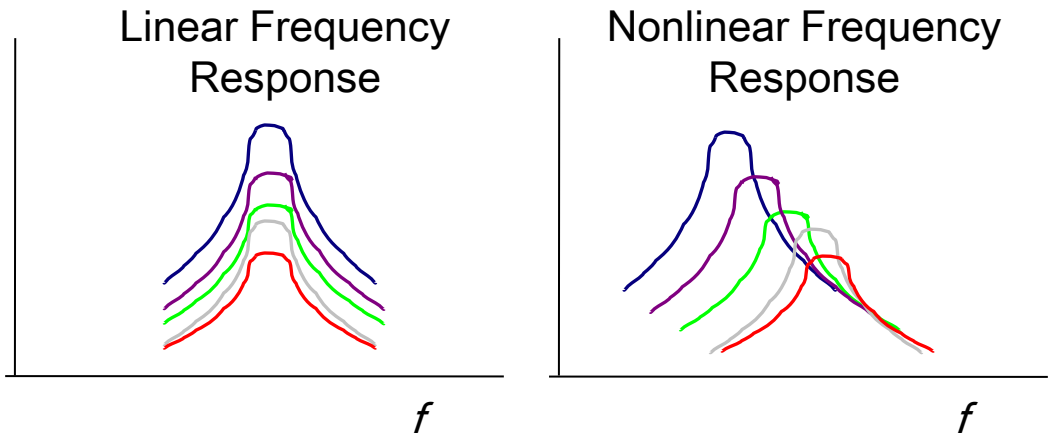
$$\frac{\partial^2 u}{\partial t^2} - c_0^2 \cdot \frac{\partial^2 u}{\partial x^2} = c_0^2 \frac{\partial}{\partial x}\left[-2\beta \cdot \left(\frac{\partial u}{\partial x}\right)^2 + \delta \cdot \left(\frac{\partial u}{\partial x}\right)^3 + \ldots \right] + H(\varepsilon, \dot{\varepsilon})$$

Nonlinear parameters

Van Den Abeele and De Visscher, 2000

$$\frac{f_r - f}{f_r} \approx C_1 \cdot \alpha \Delta\varepsilon + C_2(\beta^2, \delta)\Delta\varepsilon^2 - C_3 \cdot \alpha^2 \Delta\varepsilon^2$$

Parameters C_n are related to contribution of the classical (β, δ) and hysteretic (α) nonlinearities



CONCLUSIONS

- Electromechanical impedance shows potential in detecting and characterizing fatigue damage before onset of crack development.
- Frequency shift of impedance peaks can be used to asses fatigue damage in aluminum alloy. Magnitude of the shift correlates with damage severity.
- In the Nonlinear Resonance method, both linear and nonlinear shifts allow to detect and quantify fatigue damage

Future work

- Correlate ultrasonic data for fatigued samples with fatigue-induced changes in electrical conductivity .
- Explore integration of embedded ultrasonic methods with vibration monitoring and electrical conductivity measurements.

ACKNOWLEDGEMENTS

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