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Title: Piezoelectric Active Sensing for Damage Detection on Wind Turbine Blades

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Piezoelectric Active Sensing Techniques for Damage Detection on Wind Turbine Blades

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Abstract

Piezoelectric active sensing techniques for damage detection on wind turbine blades
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This paper presents the performance of a variety of structural health monitoring (SHM) techniques, based on the use of piezoelectric active sensors, to determine the structural integrity of a 9m CX-100 wind turbine blade (developed by Sandia National Laboratory (SNL)). Specifically, Lamb wave propagation, impedance based methods, frequency response functions, and a time series based method are utilized to analyze the condition of the wind turbine blade. The main focus of this research is to assess and construct a performance matrix to compare the performance of each method in identifying incipient damage, with a special consideration given to power consumption and issues related to field deployment. Experiments are conducted on a stationary, full length CX-100 wind turbine blade. This examination is a precursor for planned full-scale fatigue testing of the blade and subsequent tests to be performed on an operational CX-100 Rotor Blade to be flown in the field.

Motivation - Active Sensing and SHM

- Validate / update physics-based numerical models
- Estimate the current state of the blade, including detection of the onset and growth of damage
- Monitor / predict load characteristics to estimate remaining life in the presence of damage (prognostics)



Challenging Issues in Sensing System Design

- Critical state of damage is not well defined for wind turbine blades
- Low cost, low power solution with wireless capabilities
- Improved reliability in a robust electronics package
- Optimally configured and installed
  - Maximize observability while minimizing necessary hardware

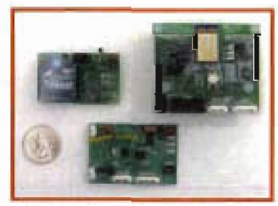

Courtesy of Wind Systems


Courtesy of gallery.pictopia.com

Active Sensing System

- Multi-scale sensing for SHM and prognostic assessment
  - Local active sensing
  - Global passive sensing
- Piezoelectric transducers are used as sensors and actuators
  - Dual use reduces the total amount of installed hardware
- Develop an integrated hardware / software solution designed specifically for wind turbine applications

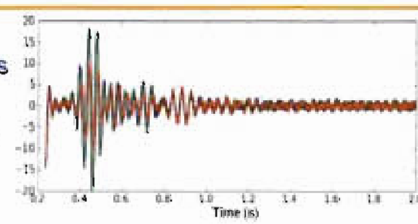
Piezoelectrics can serve as both sensors and actuators

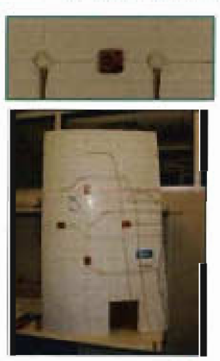


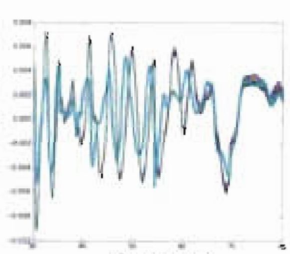
Hardware has evolved from previous experience in civil applications

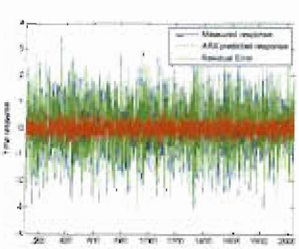
Active Sensing SHM Techniques

- Lamb wave propagations
- High frequency response functions
- Time series predictive models
  - CX-100 turbine blade 1-m section
  - Introduced simulated damage



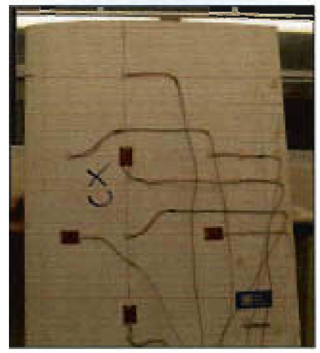




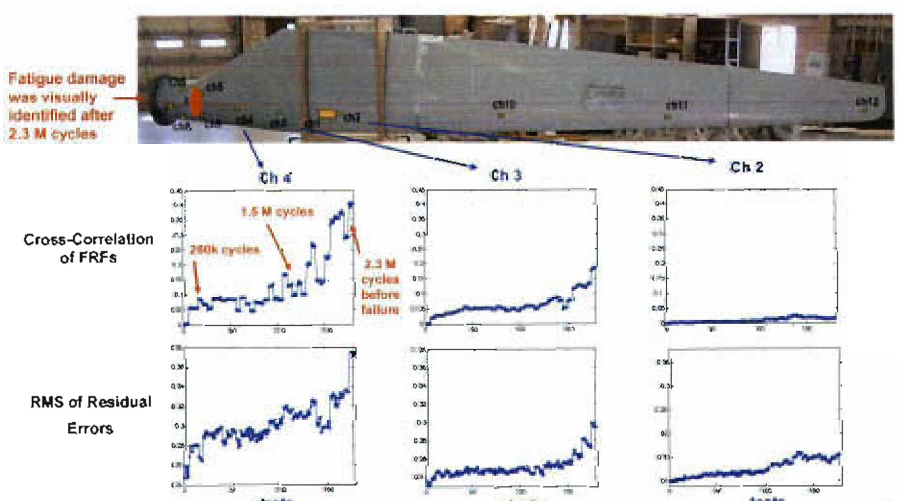


Active Sensing: Method Comparison

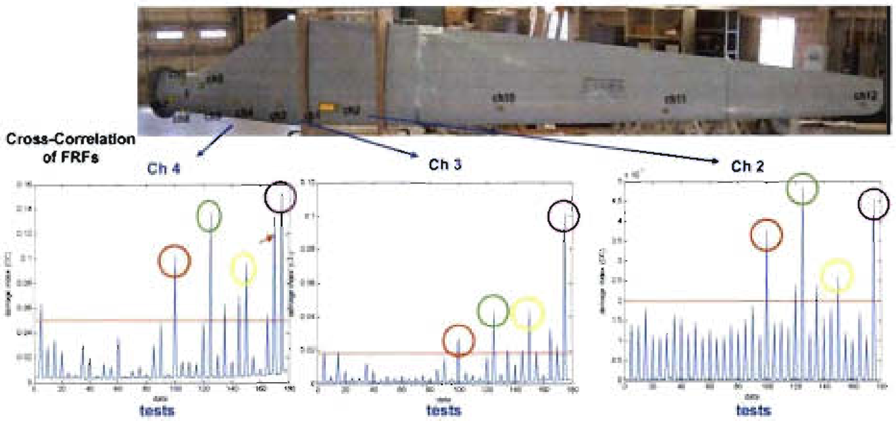
- Lamb wave propagations
  - Detect and locate damage
  - Requires higher electric power, extremely small propagating distance (< 0.5 m)
- Frequency domain (up to 80 kHz)
  - Damage localization capabilities
  - Moderate power and memory usage
- Time series analysis
  - Similar capabilities of FRF methods while requiring less measured data
  - Low power requirements
  - Electromagnetic interference



Fatigue Test: Active Sensing SHM



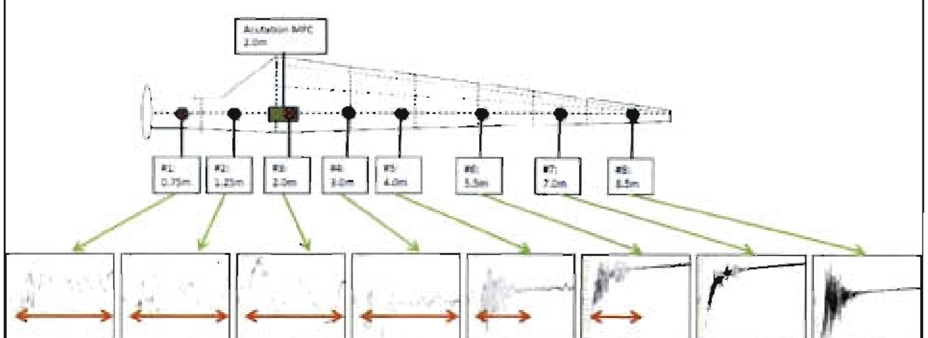
Fatigue Test: Active Sensing SHM



- Corresponds to 1.5 M cycles: acoustic emission systems also noticed changes in emission activities

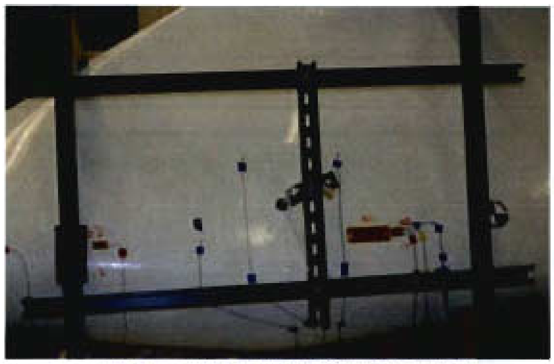
Full-Scale Blade at LANL: Active Sensing

- Compare response at various points
  - Determine effective frequency range at points along length of blade (energy dissipation)
  - 2 actuators are needed to monitor the entire blade

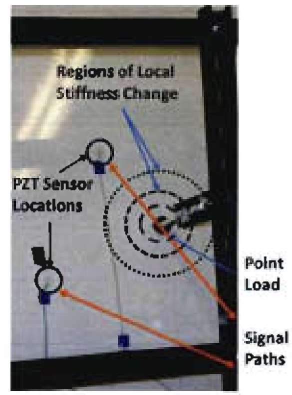


Full-Scale Blade at LANL: Active Sensing

- Local stiffness changes were imposed through the use of a point load
- The location and intensity of damage can be assessed by the response characteristics of each sensor

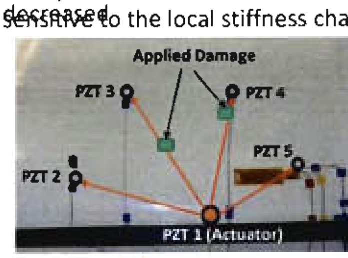


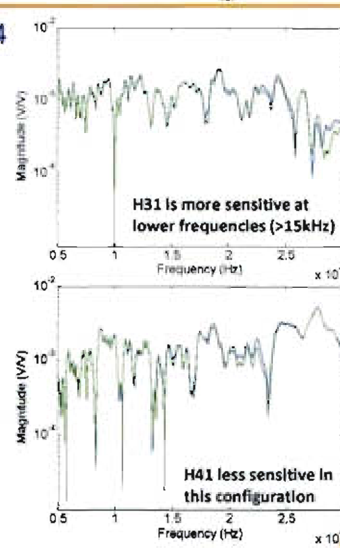
Load Frame used to Apply a Point Load to the Blade



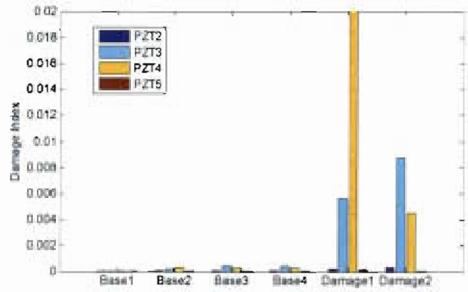
Simulated Damage – Active Sensing

- Damage was applied near PZT 3&4
- Measurements were collected for each of the sensor-actuator paths
  - PZTs 2 and 5 were insensitive to the applied damage
  - [illegible] this location, whereas PZT4 is decreased
  - As expected PZT 4 is the most sensitive to the local stiffness change





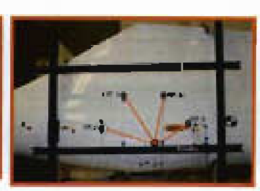
Simulated Damage – Active Sensing



- Demonstrated localization of damage using active-sensing
  - Sensing range: ~ 0.3 m radius for detecting the point load
- Extending this technique to identify damage along the spar cap and through the spar/shear web

Summary

- Several experimental investigations have demonstrated the potential of piezoelectric transducers for:
  - Structural Health Monitoring
    - Sensitive to small defects in blades
    - Immune to operational condition changes
  - Multi-scale sensing of wind turbine blades
    - Low-cost, low-power
- A wireless sensor node is being developed to integrate multi-scale sensing and SHM capabilities for damage prognosis



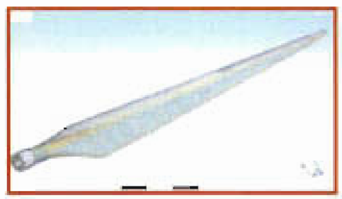
Plans for FY2011-12

FY-2011

- Full-scale fatigue tests of CX-100 (2011)
  - Collaboration with NREL, UMass-Lowell, SNL, Luna. We are currently open to other participants as well.
- NDE characterization of damage on fatigued CX-100 blade sections (2011)
  - Correlation with SHM results
- NREL's Gearbox CM round robin (2011)
- Fabrication of SHM Rotor Blade (2011)

FY-2011-12

- Integration with damage modeling and advanced data processing (2011-12)
  - Sensor location optimization
  - Prognostic analysis of blade condition
- Collaborative testing of SHM Rotor Blade with Sandia (2012)
  - Onboard SHM (LANL)
  - Operational Monitoring (SNL)
  - Large form PIV (LANL)



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