LA-UR- 10-07944

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Title: APPLICATION OF PIEZOELECTRIC ACTIVE-SENSORS FOR SHM OF WIND TURBINE BLADES

Author(s): Gyuhae (NMI) Park, INST-OFF, LANL
Stuart G. Taylor, INST-OFF, LANL
Kevin M. Farinholt, AET-1, LANL
Charles R. Farrar, INST-OFF, LANL

Intended for: 3rd Asia Pacific Workshop on Structural Health Monitoring, November 30-December 2, 2010, Tokyo, Japan

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Application of Piezoelectric Active-Sensors for SHM of Wind Turbine Blades

Gyuhae Park, Stuart G. Taylor, Kevin M. Farinholt, Charles R. Farrar
The Engineering Institute
Los Alamos National Laboratory, USA

This paper presents a variety of structural health monitoring (SHM) techniques, based on the use of piezoelectric active-sensors, used to track and monitor the integrity of wind turbine blades. Specifically, Lamb wave propagation, Impedance-based methods, frequency response functions, and a time series based method are utilized to analyze the condition of wind turbine blades. 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 field deployability. For experiments, sections of a CX100 blade were used. Different types of damage are introduced into this structure. Overall, these three methods yielded sufficient damage detection to warrant further investigation into field deployment. This paper also summarizes the SHM results of a full-scale fatigue test of 9-m CX-100 blade using piezoelectric active-sensors.

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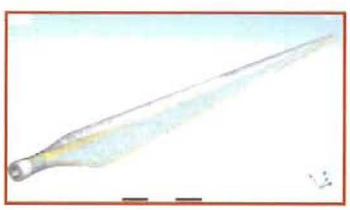
Backgrounds

- The DOE projects that 20% of the total US electrical energy supply could be wind energy by 2030.
- Los Alamos National Laboratory started an internal, 3-year research project, entitled on "Intelligent Wind Turbines."
  - Predictive Modeling
    - Structural models
    - Atmospheric models: WINBLADE
  - Advanced, multi-scale sensing
  - Model validation, uncertainty quantification

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Multi-scale sensing in IWT project

- Provide experimental data to
  - Validate the physics-based numerical model
  - Estimate the current state of the structure, including detection of the onset of damage
  - Predict the structure's load characteristics
- Required to be
  - Low cost, Low power, Wireless, in-situ desirable
  - Optimally configured and installed
  - Post-processing: load transmission, shape reconstruction, etc.

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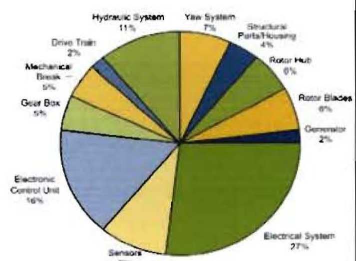
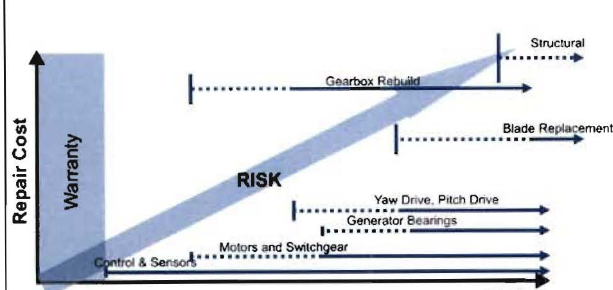
SHM of wind turbine

- Why Turbine Blades?
  - Expensive component to repair
    - Portion of Turbine cost: 15-20 %
  - Imbalance results in further damage
  - Huge, often in remote locations,



Types of Repairs on Wind Turbines from 2.5 kW to 1.5 MW

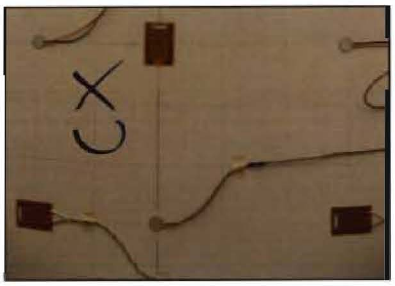
http://seekingalpha.com/article/127153-wind-turbine-energy-how-it-works-and-stocks-to-watch

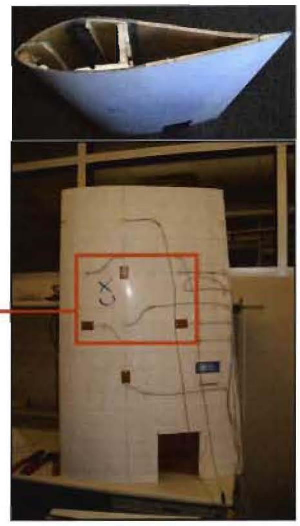


http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf

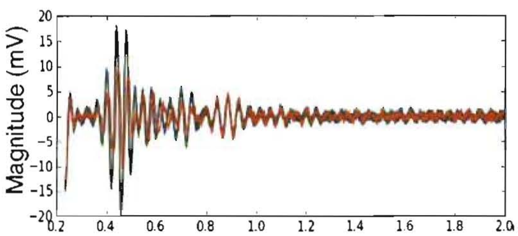
Active Sensing for SHM

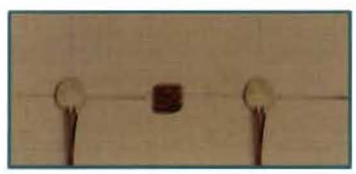
- Lamb wave propagations
- High frequency response functions
- Time series predictive models
  - CX-100 Turbine Blade 1-m Section
  - Introduced simulated damage

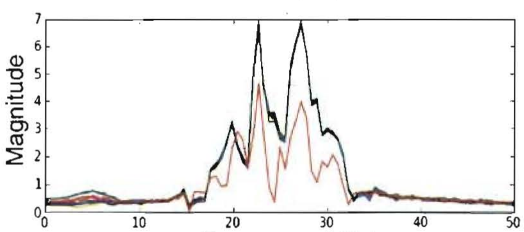


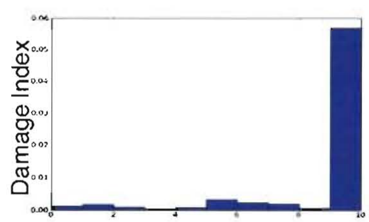


Blade Section: Lamb Wave Testing









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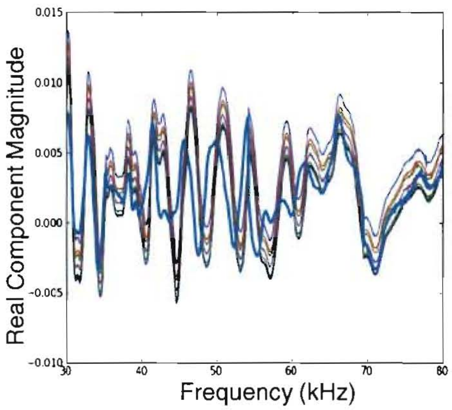
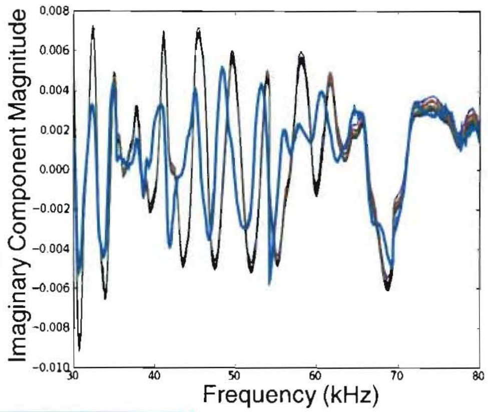
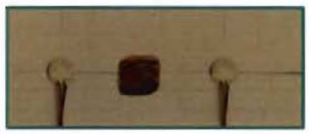
Blade Section: Frequency Response







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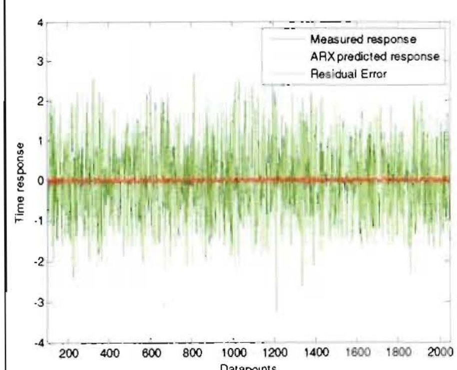
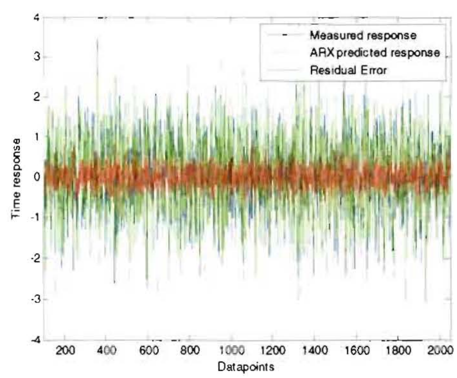
Blade Section: Time Series Analysis

Actual and Predicted Undamaged Signals (Path 1)



Actual and Predicted Damaged Signals (Path 1)



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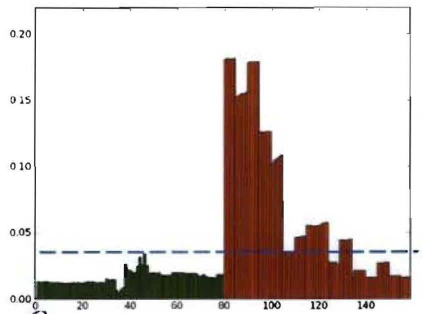
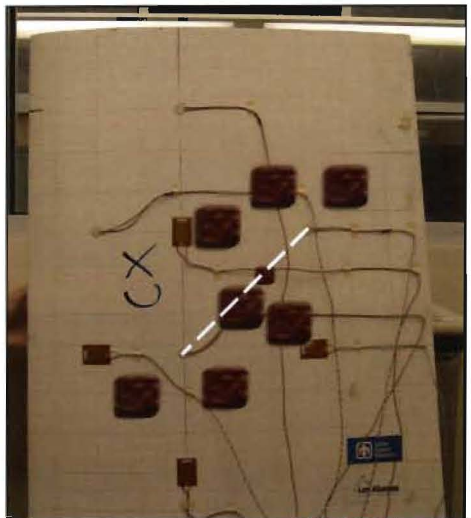
Blade Section: Time Series Analysis

- Path 1
  - Detected Damage inside sensor envelope

RMSE Plot



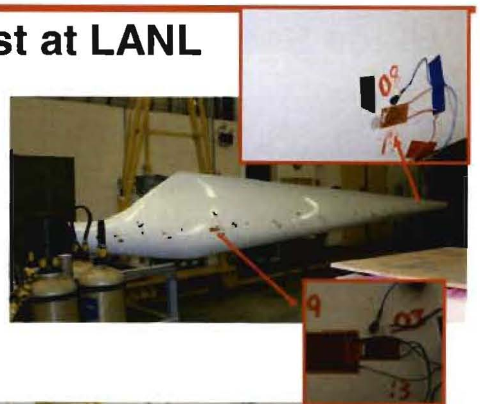


Active Sensing: Method Comparison

- Lamb wave propagations
  - Detect and locate damage
  - Requires higher electric power, extremely small propagating distance (< 0.6 m), frequency selection
- FRFs
  - Acceptable damage localization capability
  - Moderate power and memory usage
- Time series analysis
  - Show the similar capability of FRFs with less amount of data measured
  - Low power
  - EMI

Full-Scale Blade test at LANL

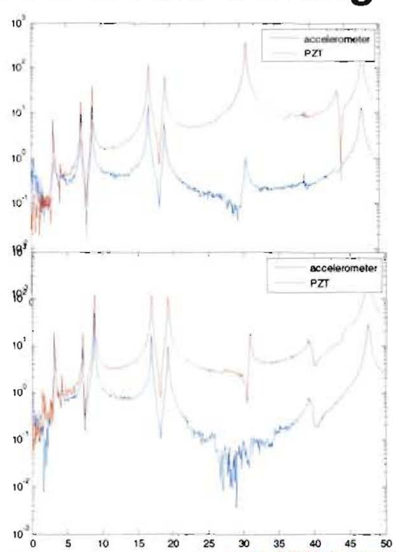
- 9-m CX-100 blade bolted to fixture
- Identified first several modes using accelerometers/ piezoelectric sensors
- Roving hammer test



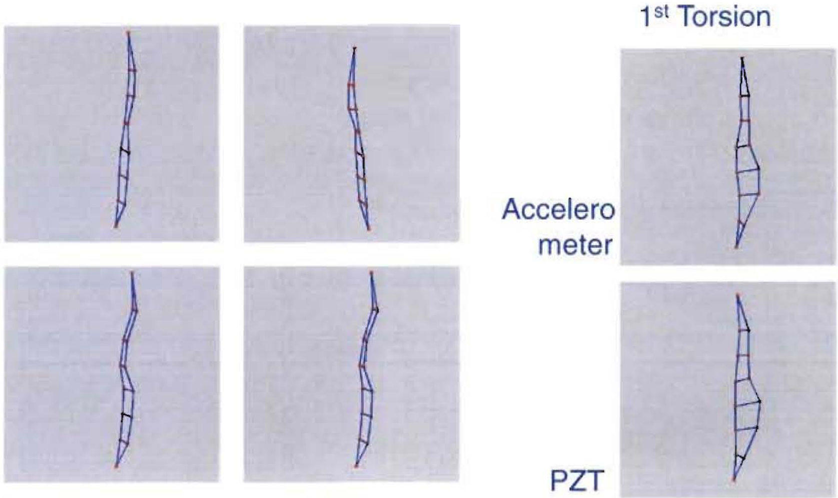
Full-Scale Blade at LANL: Modal Testing

Mode	Freq. (Hz) by accel.	Freq. (Hz) by PZT	Description
1	3.22	3.22	1st Flap Bending
2	7.14	6.22	1st Lag Bending
3	8.81	8.81	2nd Flap Bending
4	16.89	16.89	2nd Lag Bending
5	19.23	19.23	3rd Flap Bending
6	30.96	30.91	4th Flap Bending
7	44.11	44	1st Torsion

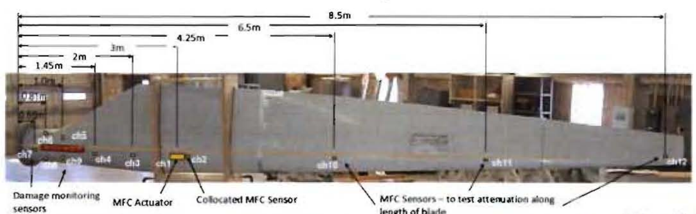
- Modal analysis was performed using SHMTools



Full-Scale Blade at LANL: Modal Testing



Sandia's Blade Fatigue test at NREL



- After 2.3 M cycles (for 3 month), damage was identified visually in the root sections.
- Measurements were taken from multiple MFC sensors
- Several Sensors (Ch. 6, 7, &10) became de-bonded during the test

Courtesy of Sandia National Laboratory

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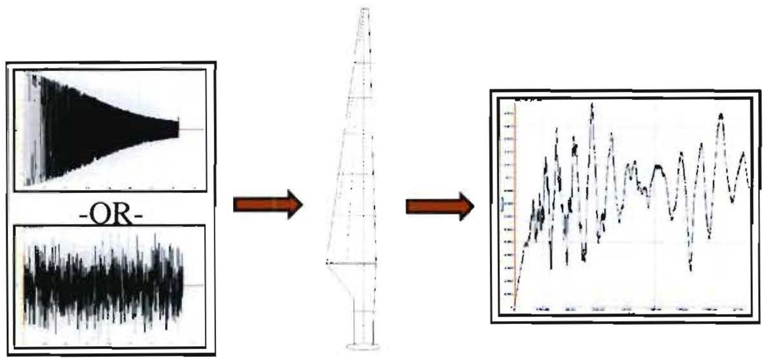
Full-Scale Blade at LANL: Active Sensing

- Actuation MFC supplied with band-limited (30 to 60kHz)
  - amplified sine chirp (150V peak)
  - burst random signal (150V peak)



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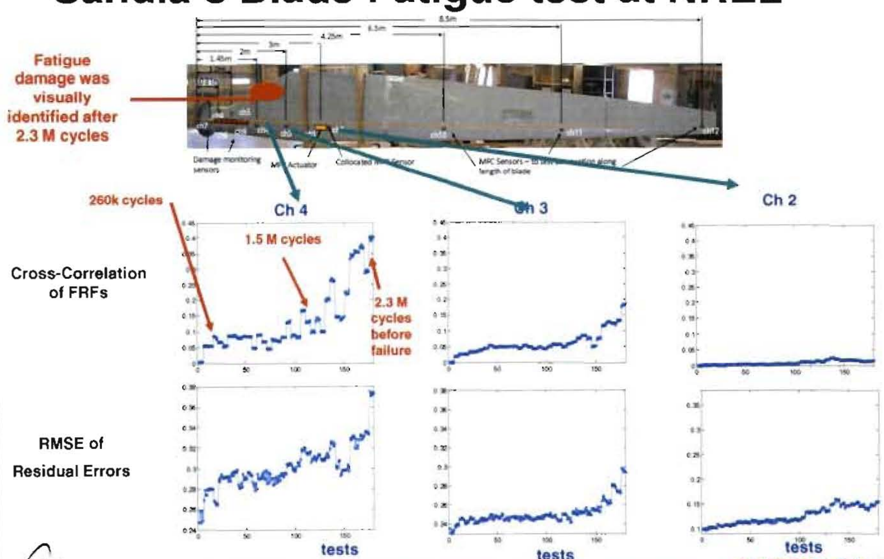
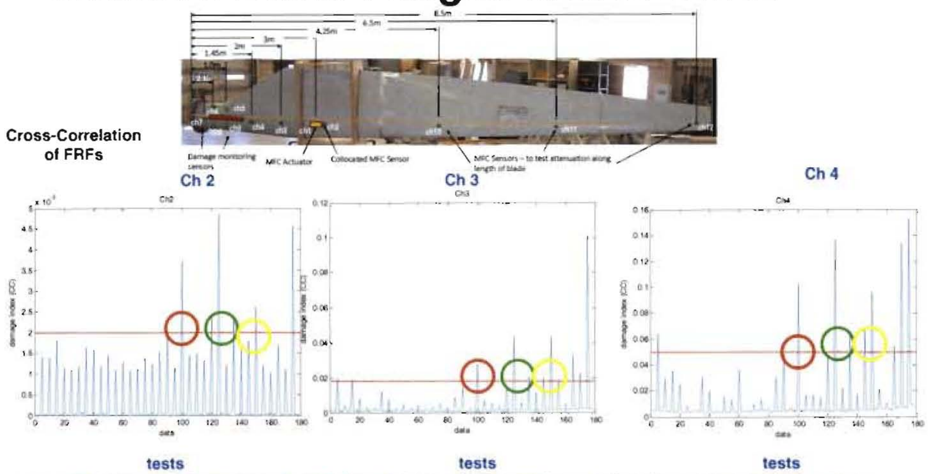


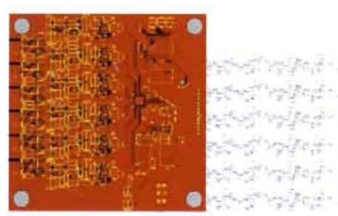
Sandia's Blade Fatigue test at NREL



- Corresponds to 1.5 M cycles, Acoustic emission systems also noticed changes in activities

Full-Scale Blade at LANL: Ongoing Work

- **Embedded Hardware for Multi-Scale Sensing**
  - Active/Passive Capable
  - Frequency Response, Time series analysis, impedance methods
  - Accommodate multiple sensing modalities
  - Sensor diagnostics
  - Higher (embedded) processing power



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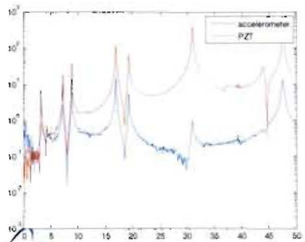
Summary

- Piezoelectric sensors utilized for SHM and low frequency sensing of wind turbine blades.
- Several methods were employed to detect structural damage
- Future work includes
  - Improve ability to locate multiple damages
  - Full-scale field demonstration with embedded wireless hardware
  - Load transmission, tip defection



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Acknowledgements

- The authors also thank Mark Rumsey and Jon White from the Wind Energy Technology Department at Sandia National Laboratory for their support and guidance on this study.