University R&D in Condition Monitoring Plus

School of Mechanical Engineering
Purdue University
West Lafayette, IN

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PURDUE UNIVERSITY

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PURDUE Center for Systems Integrity

Relevance of R&D

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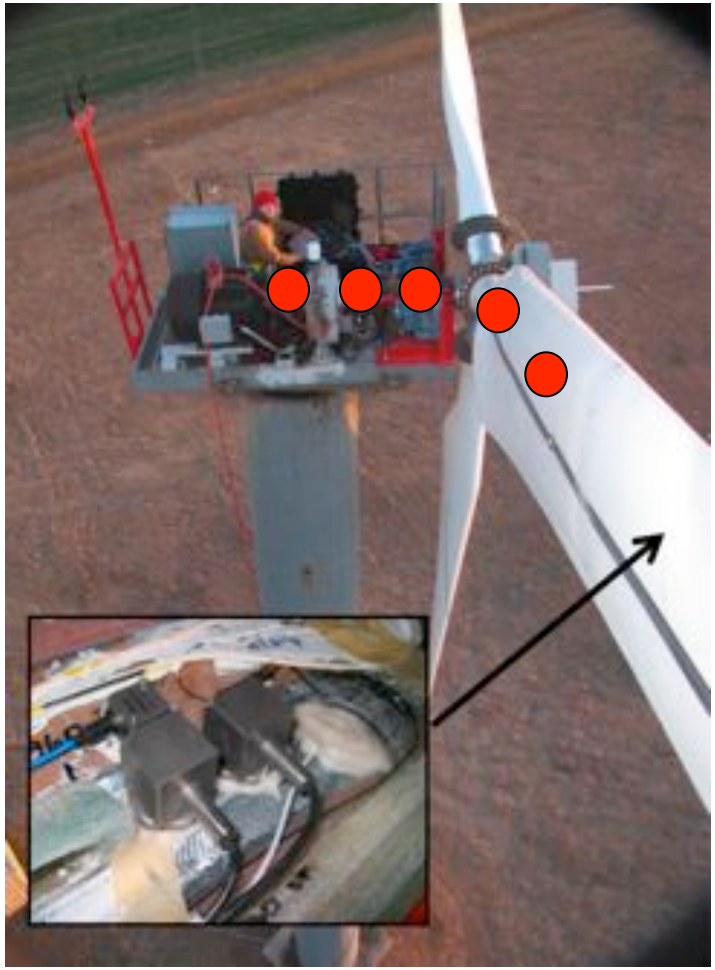
It is the uncertainties in loads, system dynamics, physics of failure, etc. that dominate reliability concerns and risk in wind power plants.

"The major difference between a thing that might go wrong and a thing that cannot possibly go wrong is that when a thing that cannot possibly go wrong goes wrong it usually turns out to be impossible to get at and repair."

Douglas Adams, 1952-2001

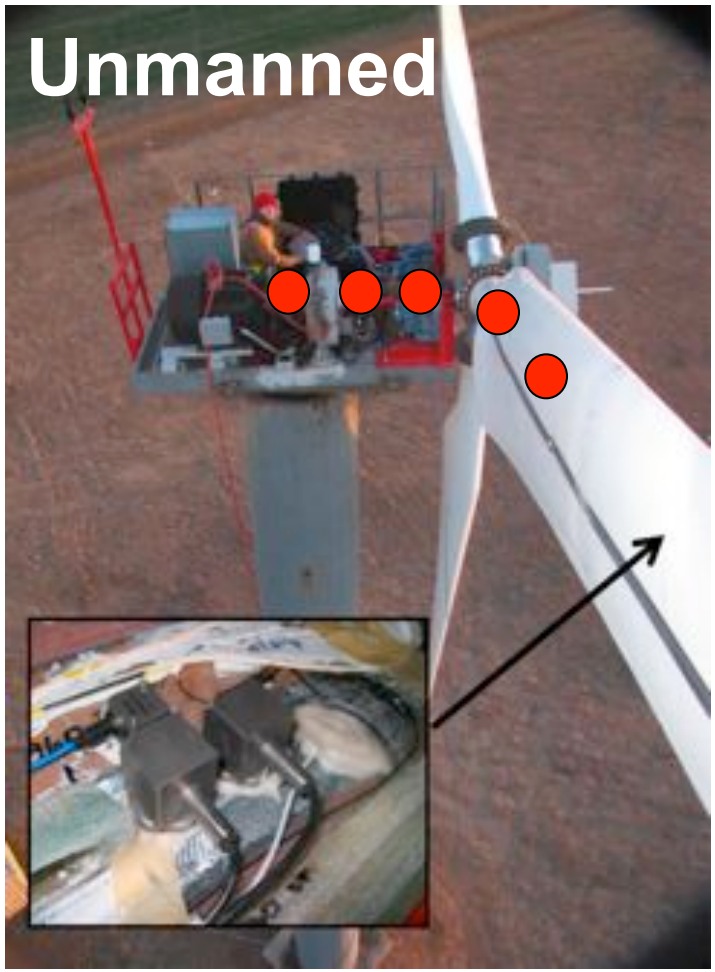
New ways to acquire, analyze, and act upon health data are needed throughout the lifecycle.

Condition Monitoring Plus



USDA-Agricultural Research Service
Micon turbine with “smart” blade

Condition Monitoring Plus



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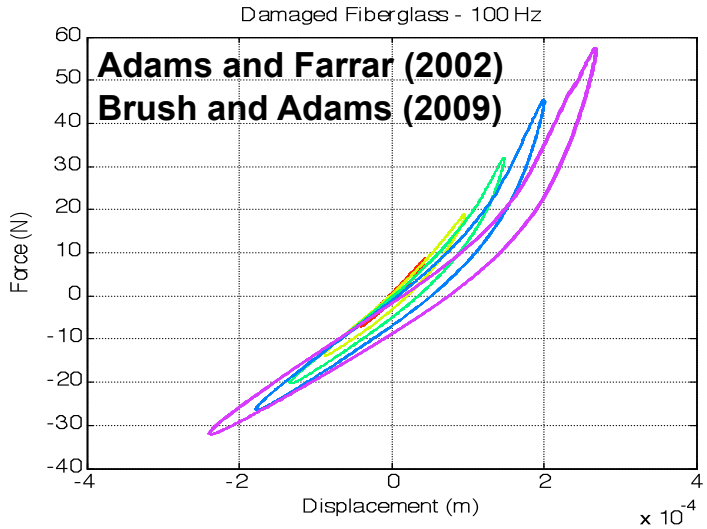
Micon turbine with “smart” blade

Inspection of Blades

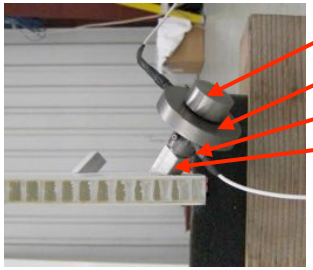
Composites turbine blades

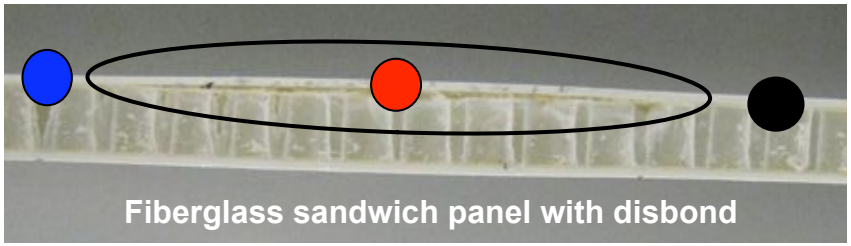
Courtesy TPI Composites



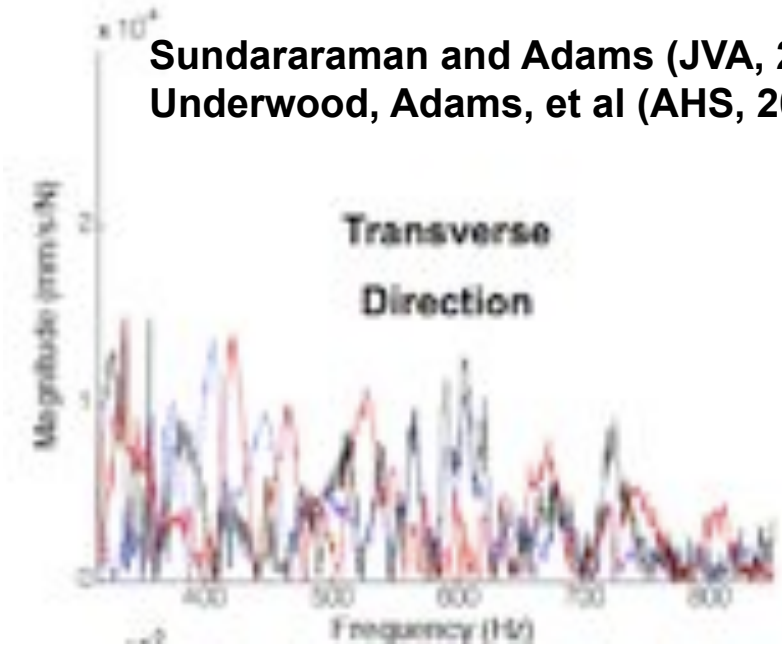
Current work (SBIR)

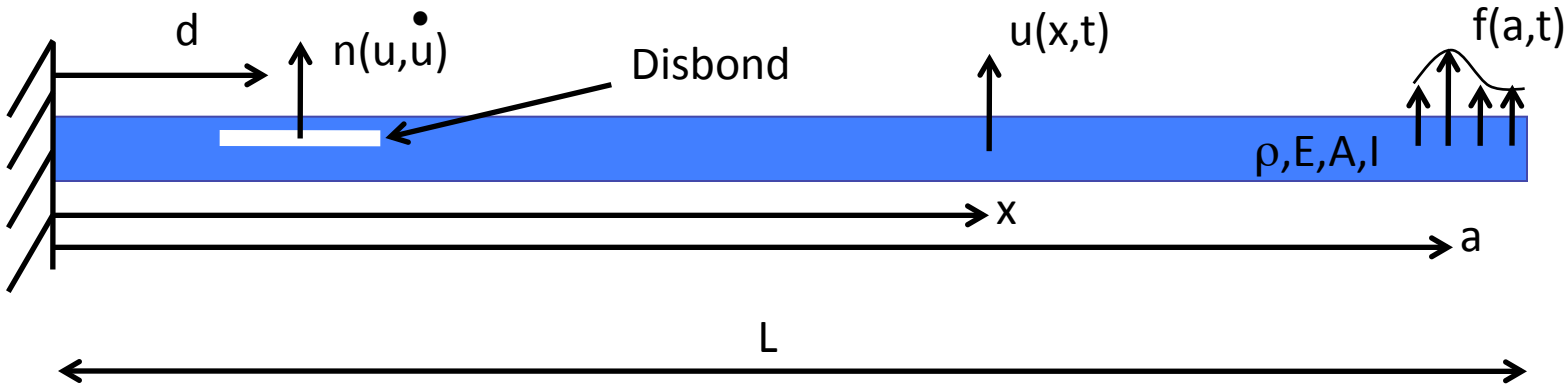
3-D Nonlinear Spectroscopy





Sundararaman and Adams (JVA, 2009)
Underwood, Adams, et al (AHS, 2009)





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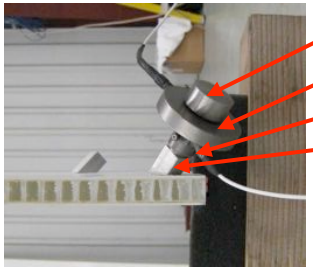
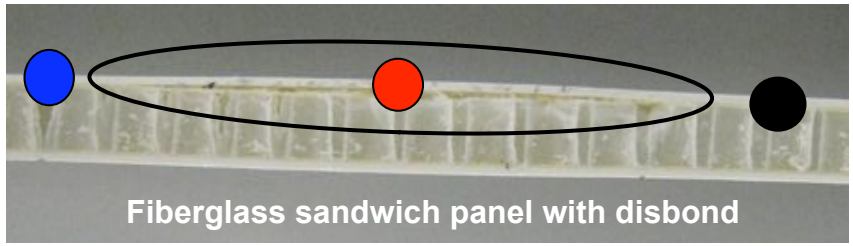


50 g mass
Piezoelectric actuator
Impedance head
Aluminum base



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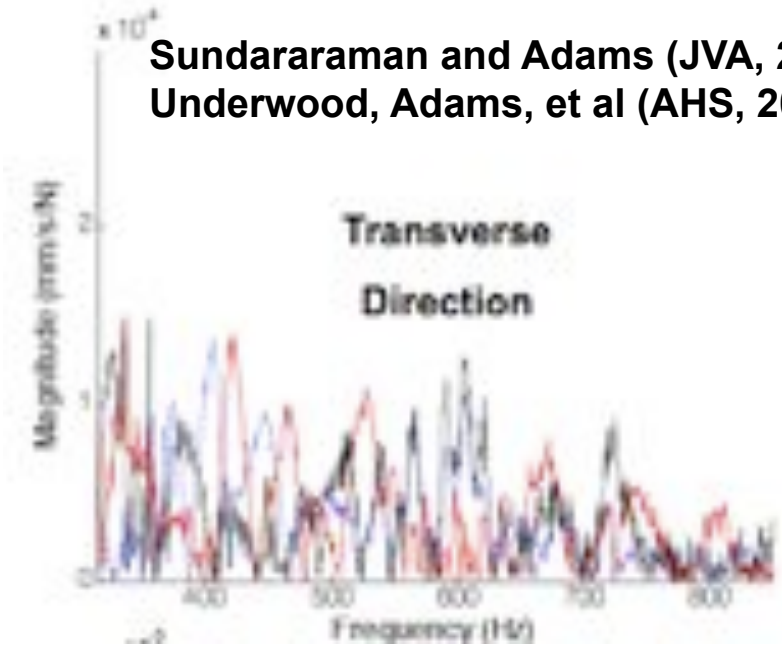
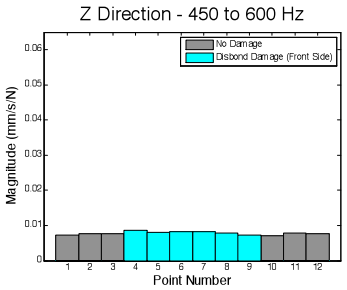
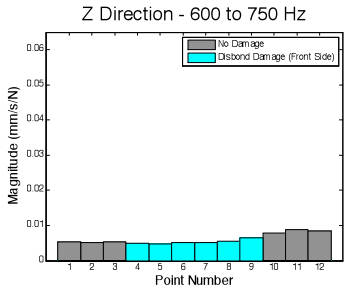
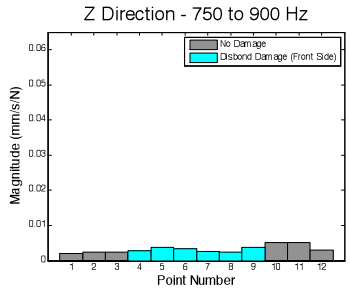




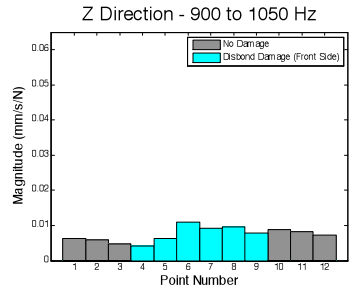
350-500 Hz



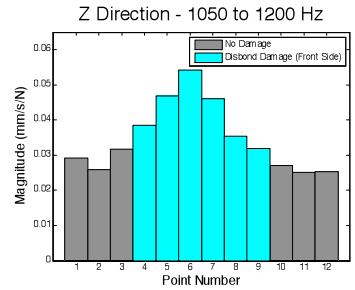
600-750 Hz



750-900 Hz

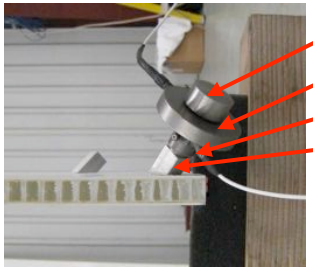


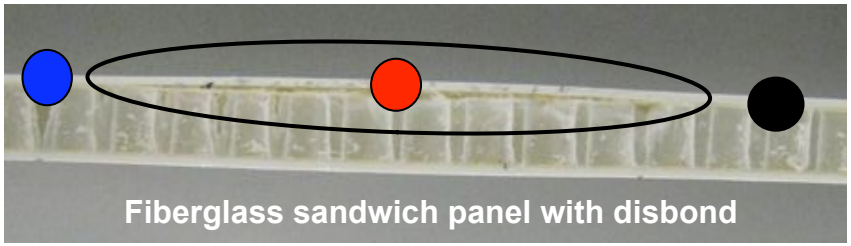
900-1050 Hz

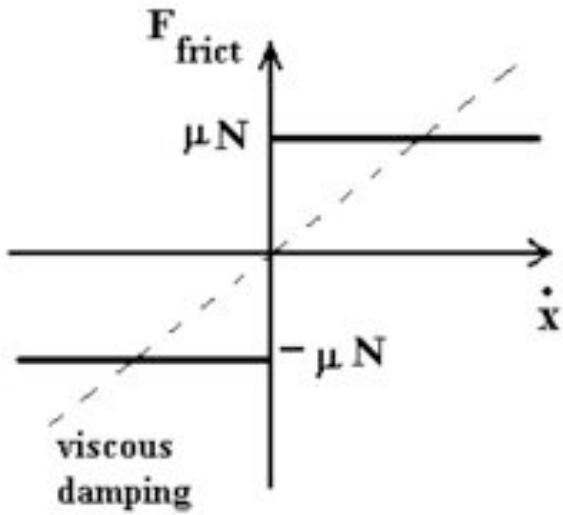


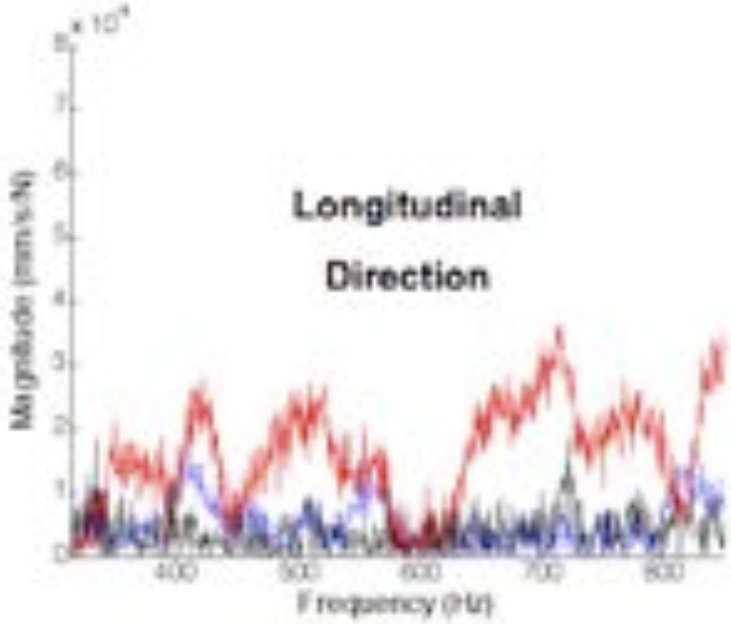
1050-1200 Hz

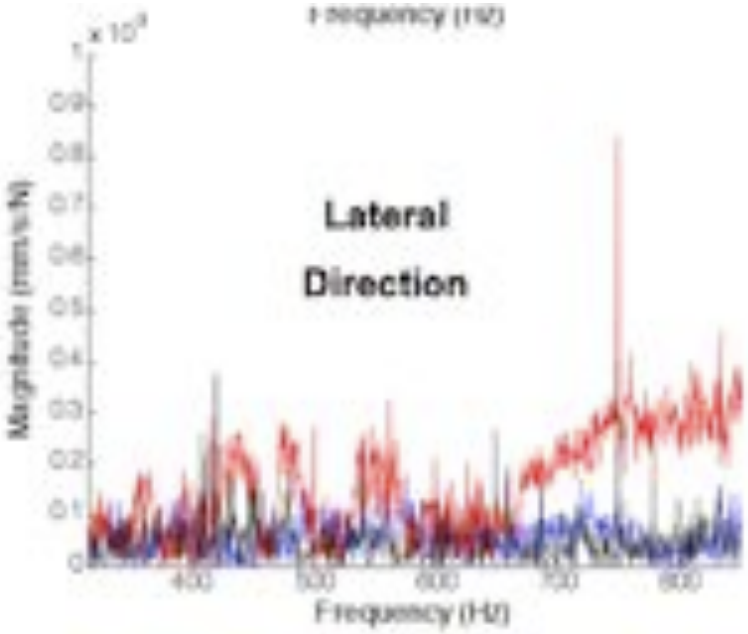
3-D Nonlinear Spectroscopy



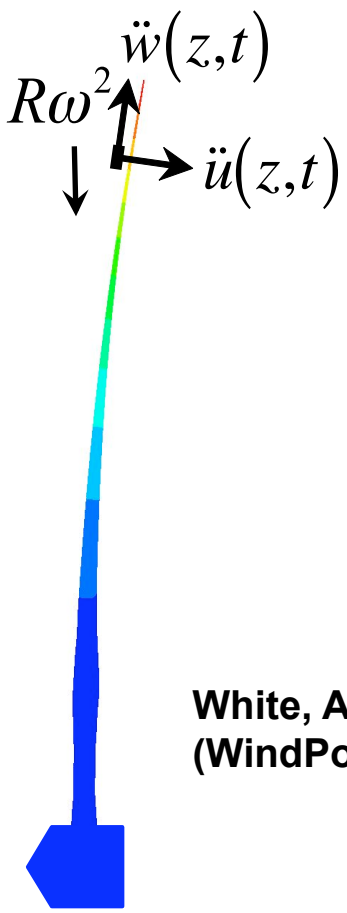




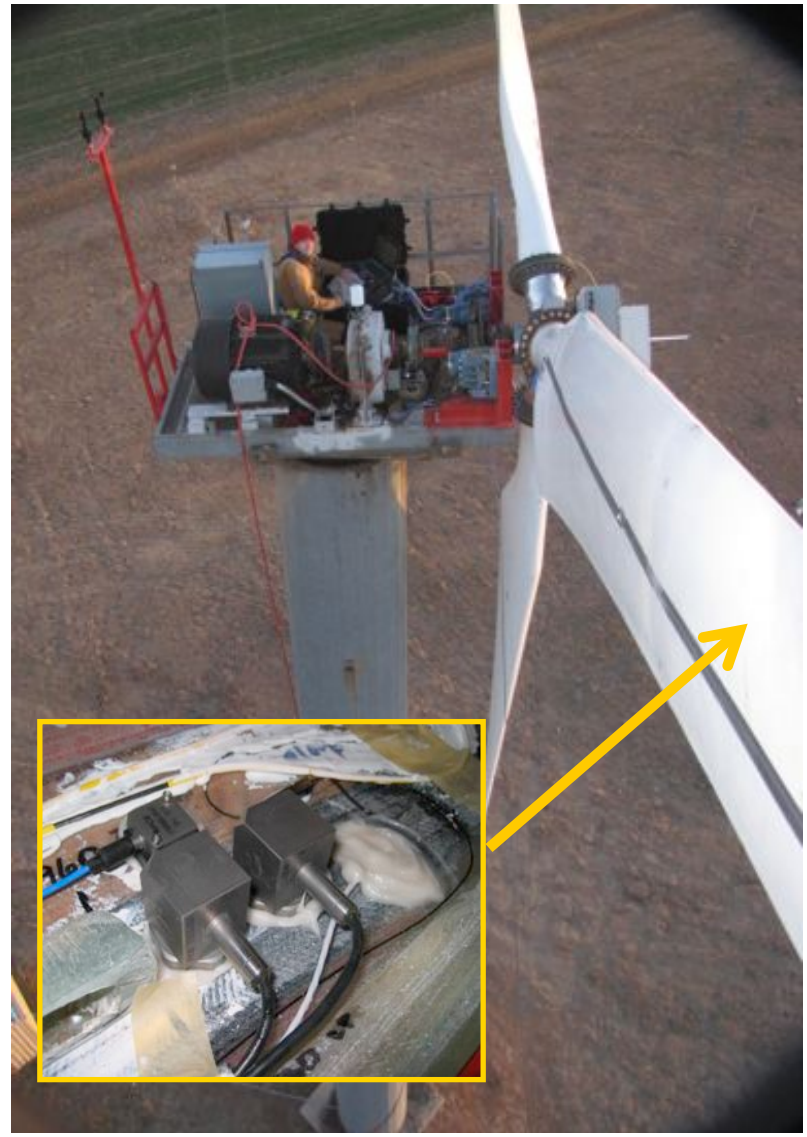




Operational Monitoring I



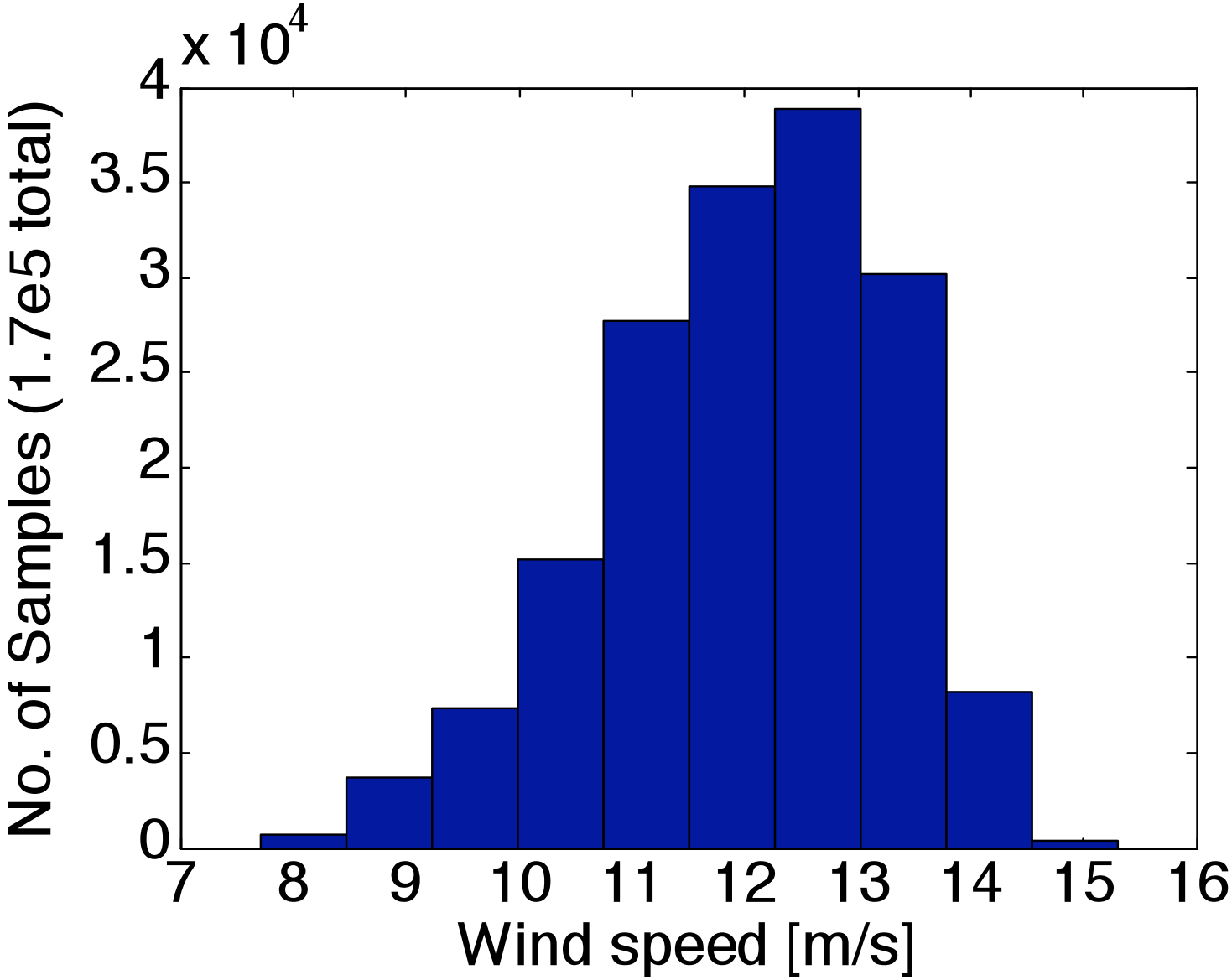
White, Adams, Rumsey, and Zayas (WindPower, 2009)



Centripetal acceleration components are measured and used to estimate slope

Operational Monitoring I

Operational Monitoring I



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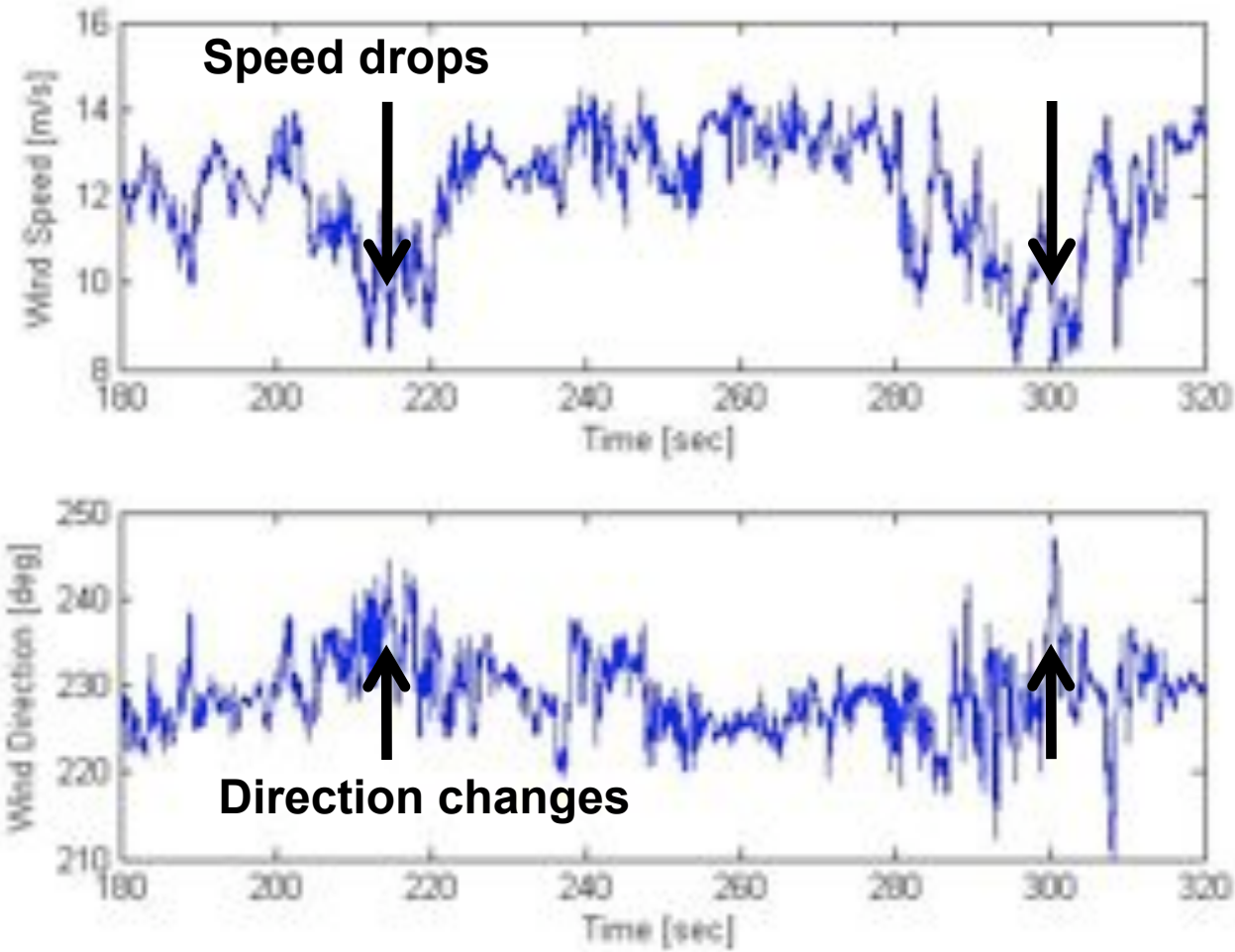
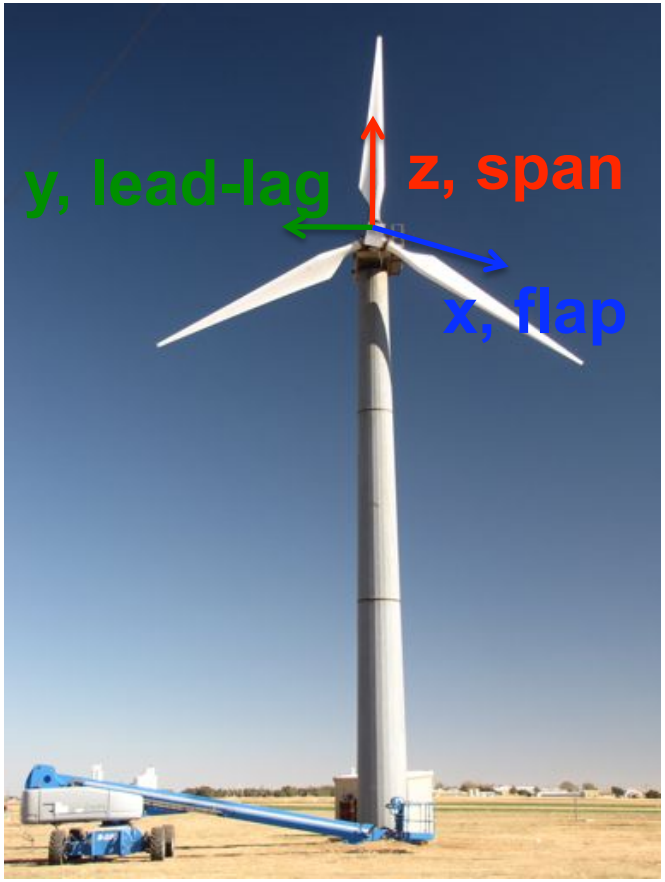


Operational Monitoring II

Static acceleration components are due to mean wind loading and rotation, and dynamic components are rotationally and structurally dependent – frequency response can be estimated.



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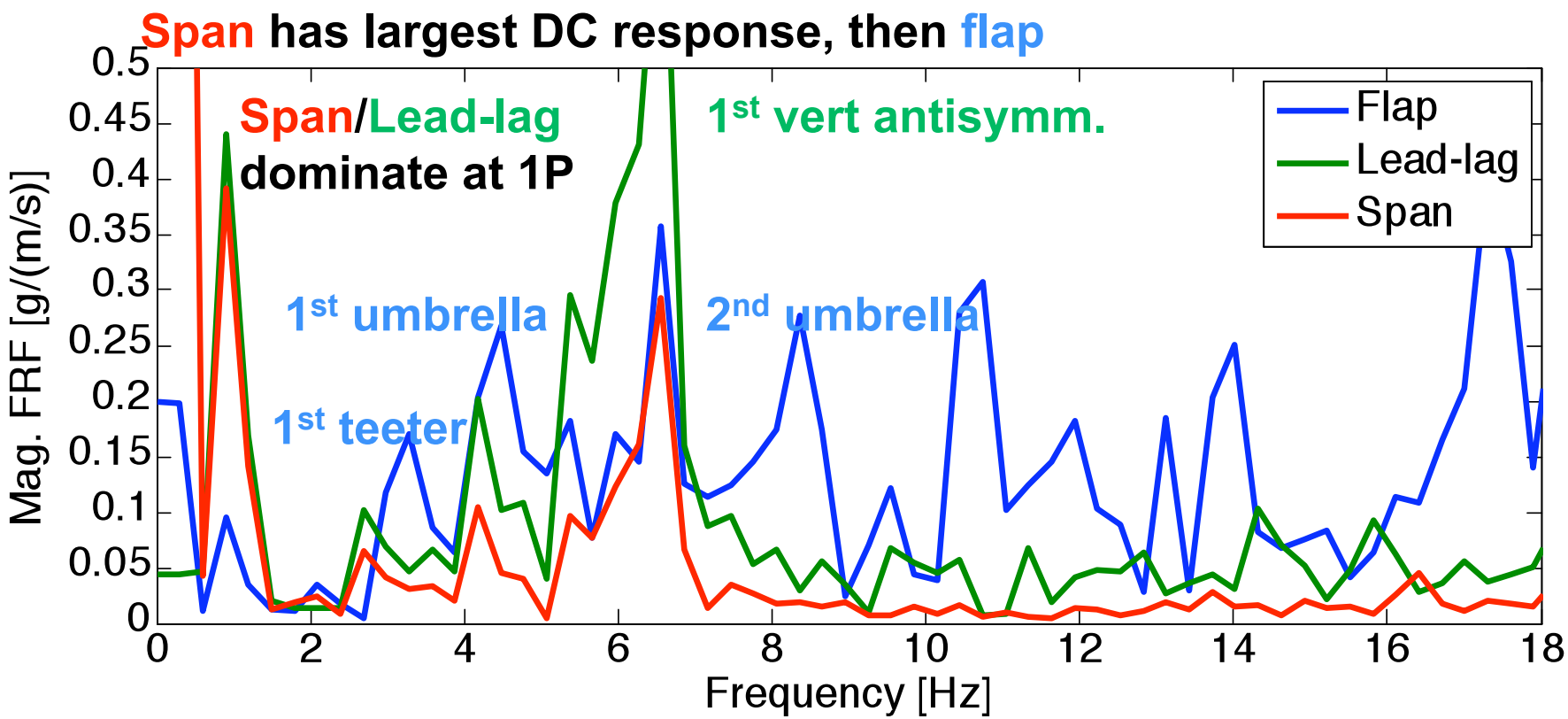
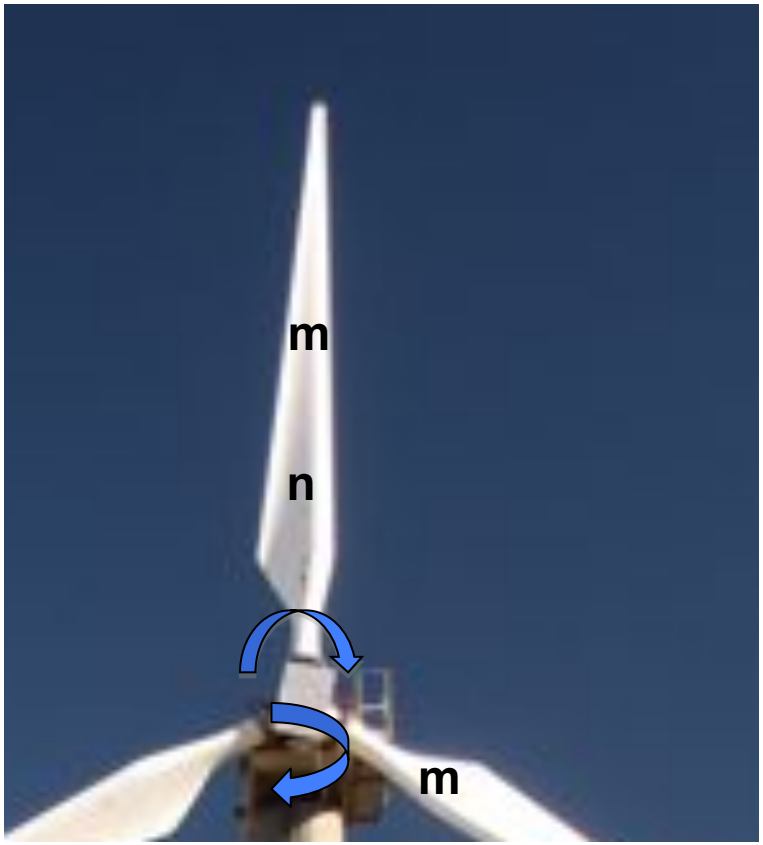


Operational Data Processing

These frequency response functions can be used for both damage monitoring in the blades (and boundary conditions) in addition to feedback and potentially feedforward control.

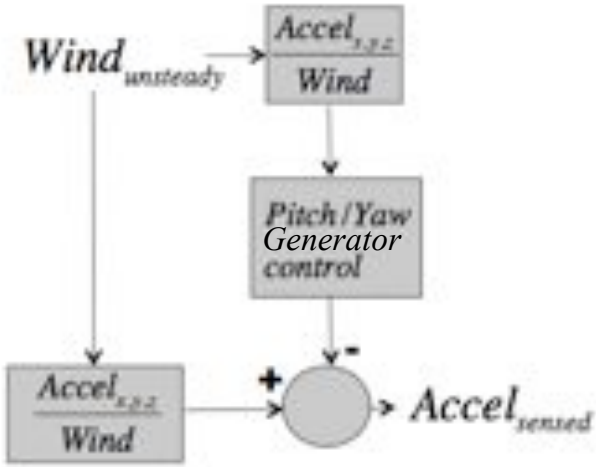


Damage monitoring

Yang and Adams (2004)

$$\frac{\partial H_{p,q}}{\partial K_{m,n}} = -\left(H_{p,m} - H_{p,n}\right)\left(H_{q,m} - H_{q,n}\right)$$

Feedforward control



Condition Monitoring

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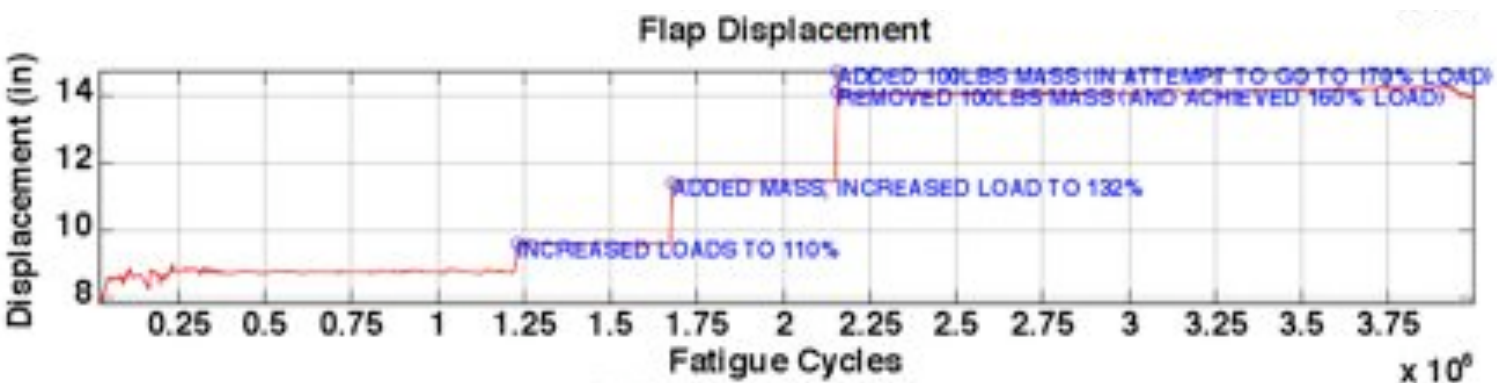
Johnson and Adams (MSSP, 2007)
White, Adams, and Rumsey (AIAA, 2008)

Fatigue to failure test of TX-100 blade at NREL in Boulder, CO (Universal Resonant Exciter)



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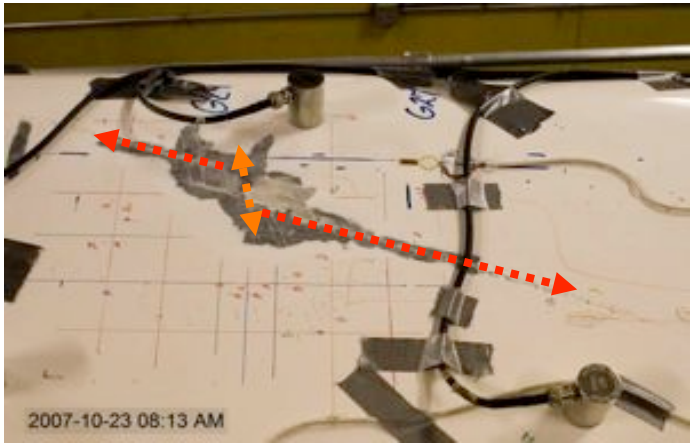
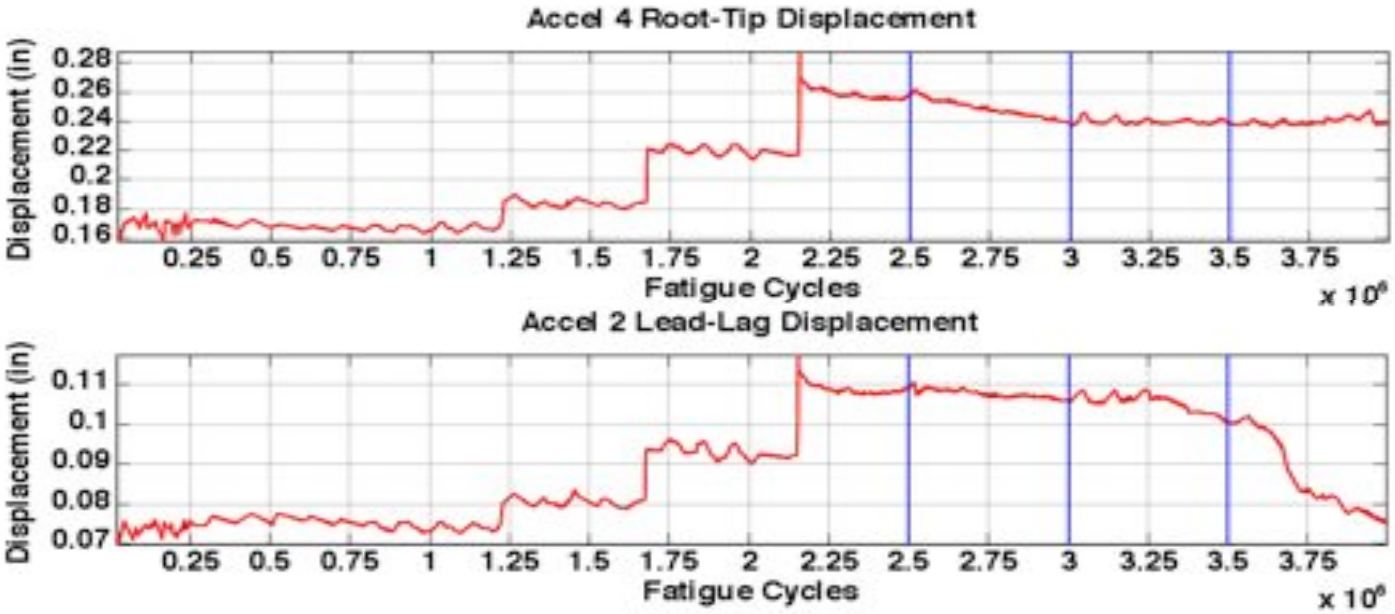
4 M Cycles 20° Crack





Gearbox Diagnostics

Many gearbox faults stem from misalignment due to installation and other low-frequency (2X, 3X) events; it was shown that dynamic torque sensing is sensitive to these precursors and that torque exhibits less statistical variation for diagnosis.

Torque

min = 0.4451

max = 0.6183

$\bar{x} = 0.5300$

$\sigma = 0.0561$

$\boxed{\sigma = 10.58\% \text{ of } \bar{x}}$

Acceleration

min = 0.1787

max = 0.3170

$\bar{x} = 0.2216$

$\sigma = 0.0515$

$\boxed{\sigma = 23.24\% \text{ of } \bar{x}}$

Less variation in torque measurement at 24X is critical for diagnostic probability of detection

$$\frac{x - \bar{x}}{\sigma}$$

Lopez, Adams, et al (JSV, 2009)

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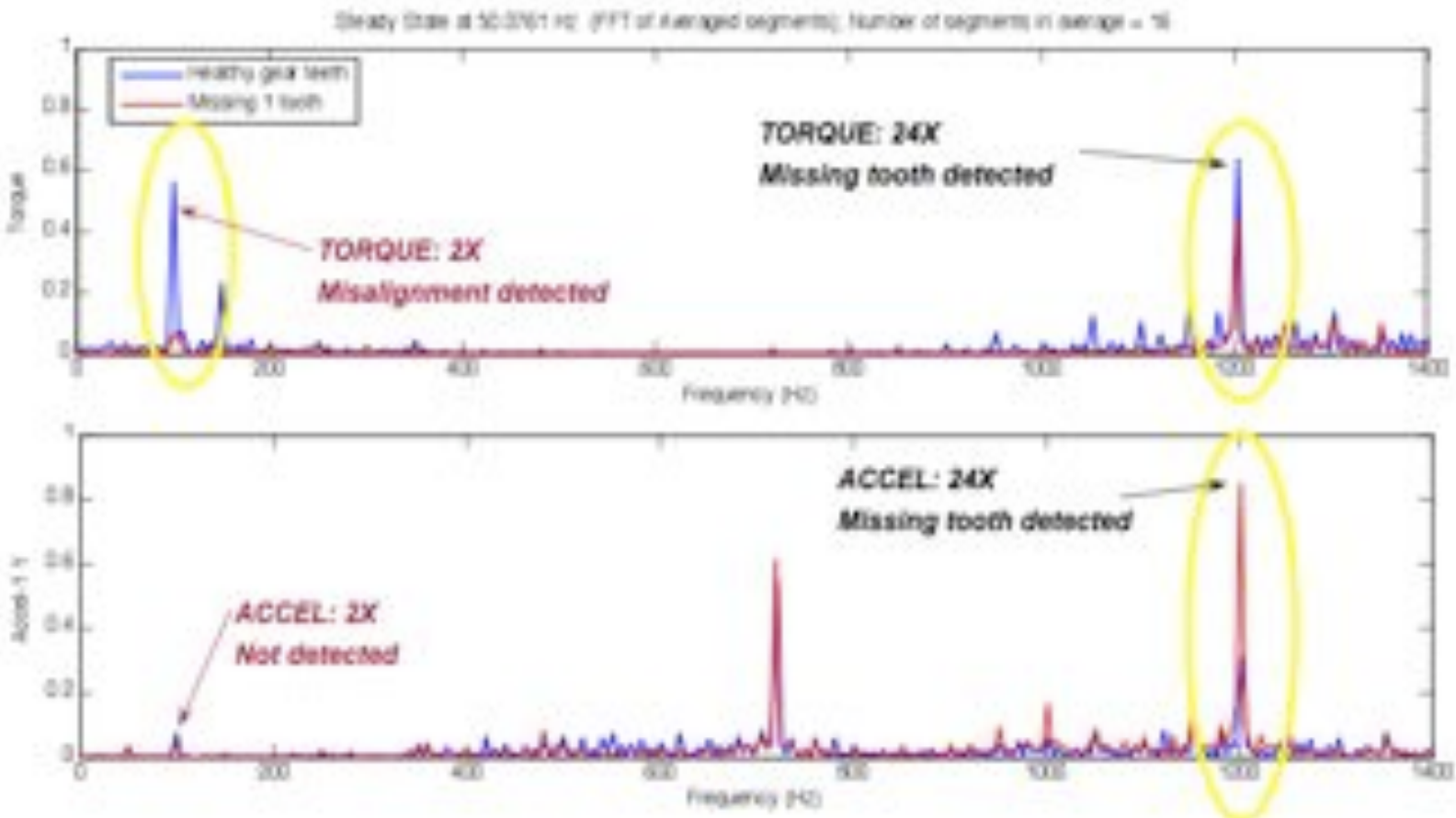
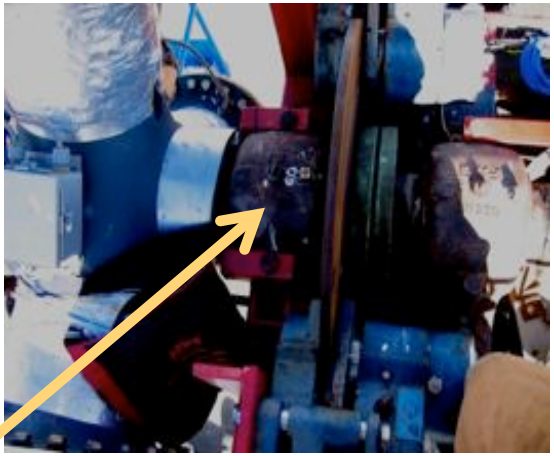


Other Examples



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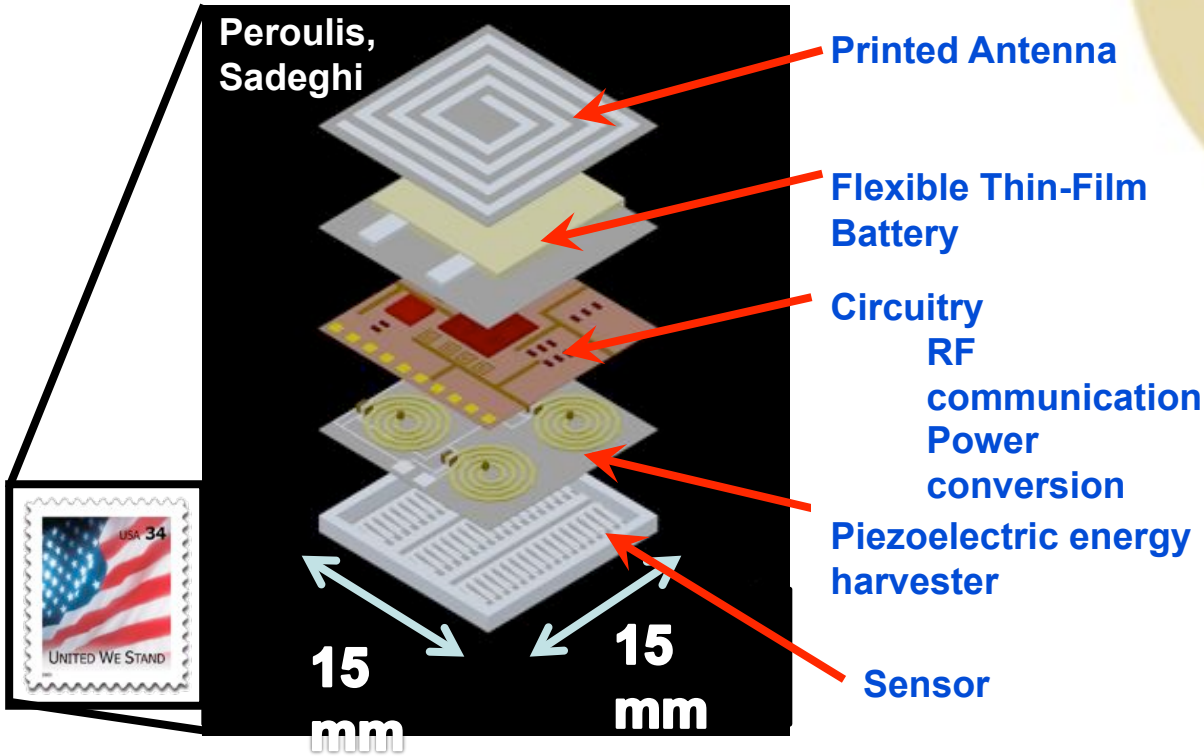

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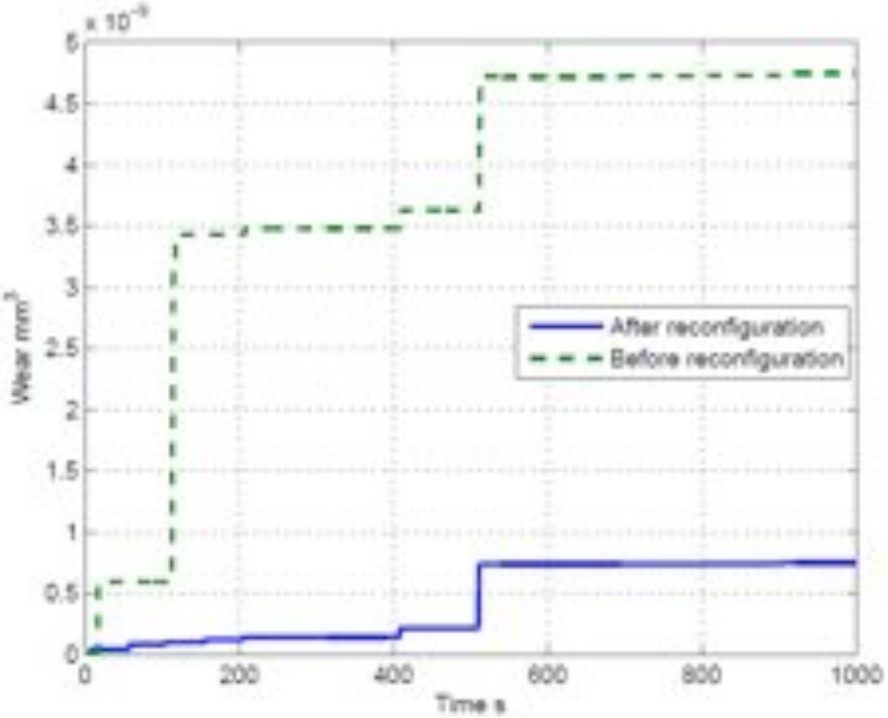

Mahulkar, Adams, and Derriso (DSCC, 2009)

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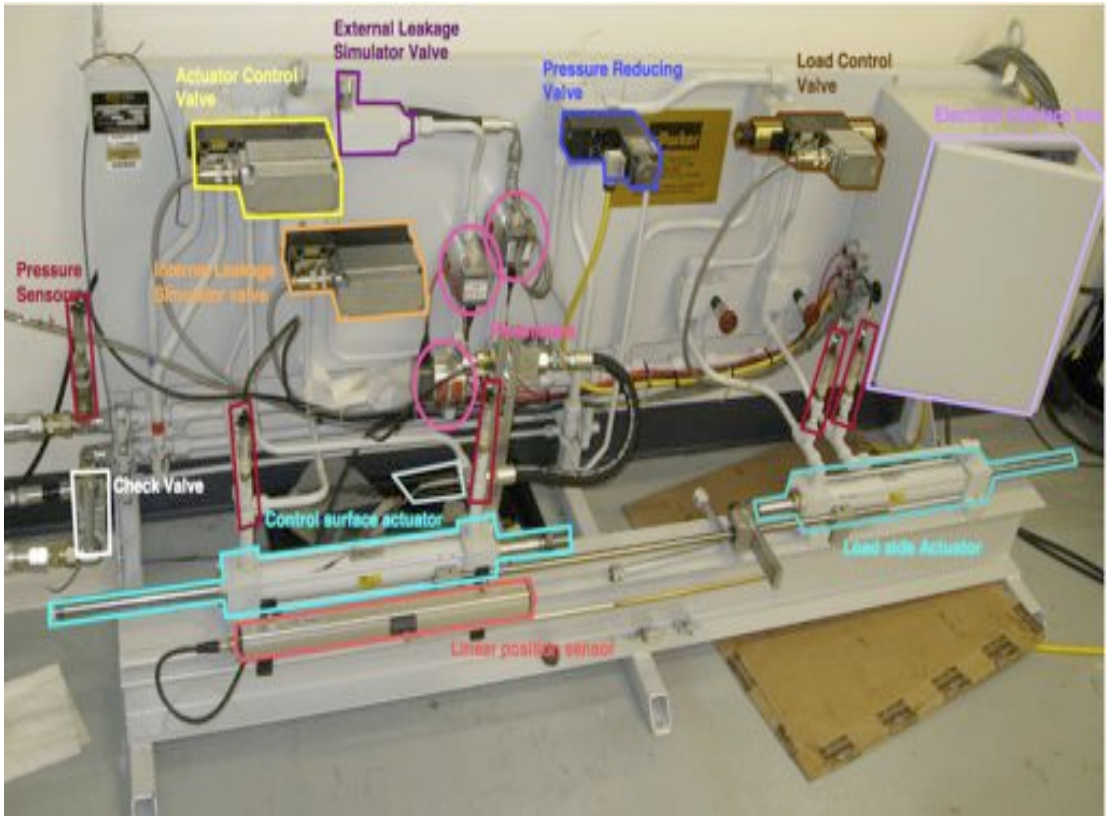

A Role for Universities

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Delivery (Technology Solutions)

Partnership with small business (SBIR, STTR)
Prototypes and entrepreneurship (ARPA-E)
Consortia with manufacturers and owners/operators (bearings, etc.)
Contractual research and intellectual property

Training (Students and continuing education)

Internships (Undergraduate and graduate students)
Facility usage (Access to wind turbines, wind farm data)
Advisory committees (Design/experimental courses, thesis committees)
Short courses and modules (Online delivery, retraining)

Discovery (Cross-cutting, Relevant Research)

Modeling/simulation/design (Physics of failure, design/sensor optimization)
Sensing/actuation (MEMS, energy harvesting, flow & blade control)
Data interrogation (Statistical signal processing, nonlinear dynamics)
Embedded systems/algorithms (Hardware in loop, computational algorithms)
Multi-scale prediction and control (Feedback/feedforward, prognosis)

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