Fiber Optic Sensors and the Sensor Blade Collaboration Between Micron Optics and Sandia National Laboratories

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Where Technology and Performance Resonate

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Wind Turbine Blade Monitoring: Project Overview

- Micron Optics Inc. (MOI) teamed with:
  - Sandia National Laboratories (SNL)
  - TPI Composites
  - Purdue University
  - Aither Engineering
- Objectives:
  - Implement all party's sensing technology in a wind turbine blade at the time of blade manufacturing
  - Assess the performance of the sensing systems throughout the life of the wind turbine blade
  - Identify issues and challenges of incorporating sensing systems in the next generation of wind turbine blades

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Contents

- Sblade Fabrication and Sensor Installation at TPI Composite's Warren, Rhode Island Manufacturing Facility
- Sblade Systems Verification and Calibration at Bushland, Tx. Test Facilities
- Sblade Configuration, Installation and Operational Testing on Turbine
- Accelerated Fatigue Life Cycle Testing at National Wind Turbine Test Facility (NREL)
- Conclusions

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Wind Turbine Monitoring Overview
Wind Turbine Testing & On-Line Monitoring

- **Design Verification & Testing**
  - Ultimate strength & fatigue
  - Design verification & improvement
  - Qualification & compliance testing
- **Blade Monitoring**
  - Static & dynamic loads (blade root & full length, wind speed, turbulence, etc.)
  - Surface stresses
  - Blade deflection (determine shape profile and avoid tower strikes)
  - Pitch control
  - Vibrations (frequencies & modal response)
  - Surface condition (ice, dust, fouling)
- **Tower & Foundation**
  - Loads, bending & torque
  - Vibration modes

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Sblade Fabrication and Sensor Installation

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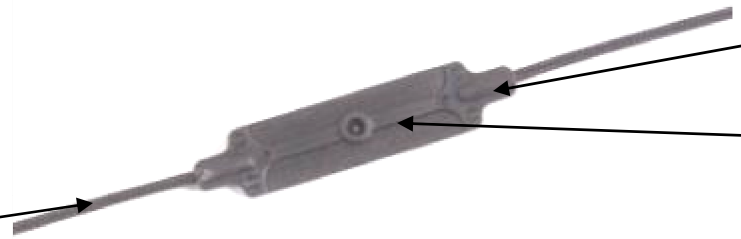
Wind Turbine Blade Monitoring: Sensor Installation Overview (Sensor Type)



Protective plastic carrier and epoxy molding pre-form.

FBG underneath protective groove.

Optical fiber in protective, braided jacket.

Double ended FBG calibrated temperature sensor located along the length of the blade.

Single ended FBG calibrated temperature sensor located at blade tip.

Accelerometer added during fatigue testing.

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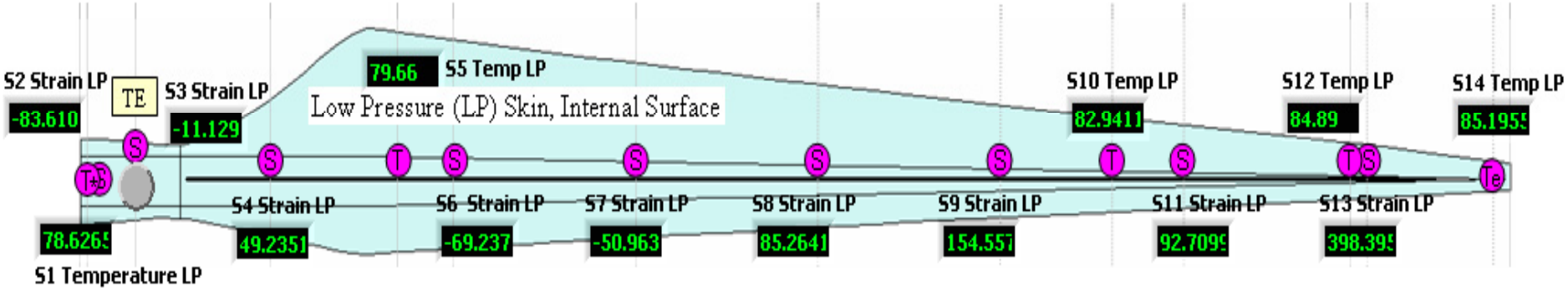
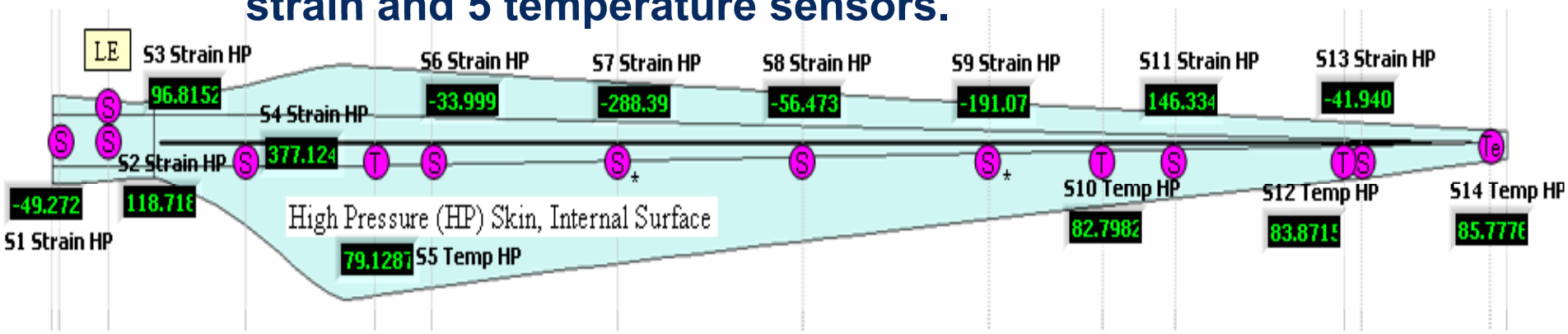
Wind Turbine Blade Monitoring:
Sensor Installation Overview (Sensor Layout)



Low Pressure Skin - All sensors are located on one fiber optic cable and connected to channel one. 9 strain and 5 temperature sensors.



High Pressure Skin - All sensors are located on one fiber optic cable and connected to channel two. 10 strain and 4 temperature sensors.

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Wind Turbine Blade Monitoring: Sensor Installation Overview (TPI Composites)

- Sensor installation occurred during blade construction.
- Blade is composed of balsa wood, carbon fiber, epoxy and fiberglass.
- Sensor types include FBG strain and temperature sensors, foil strain gages, resistive temperature devices (RTDs) and accelerometers.

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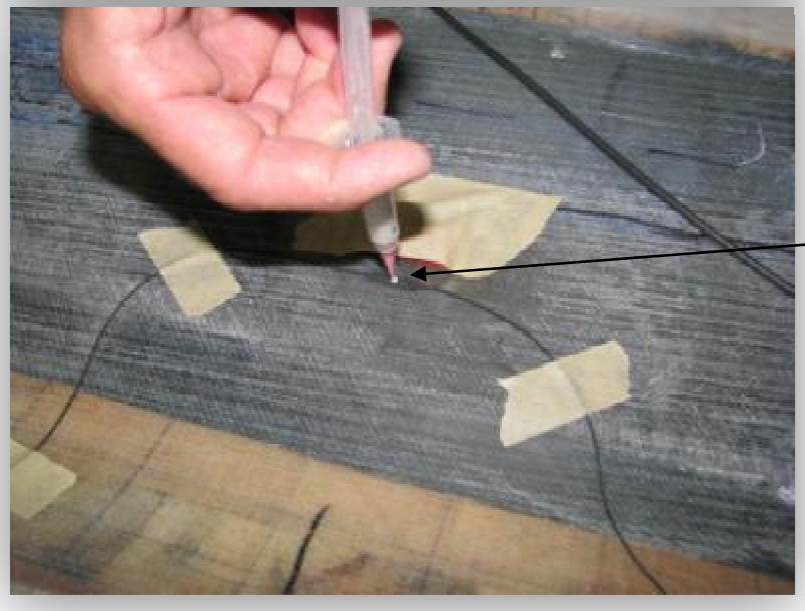
Wind Turbine Blade Monitoring: Sensor Installation Overview (TPI Composites)

Sensor array delivered to TPI assembled and ready for installation.



Attachment of the FBG strain gage.

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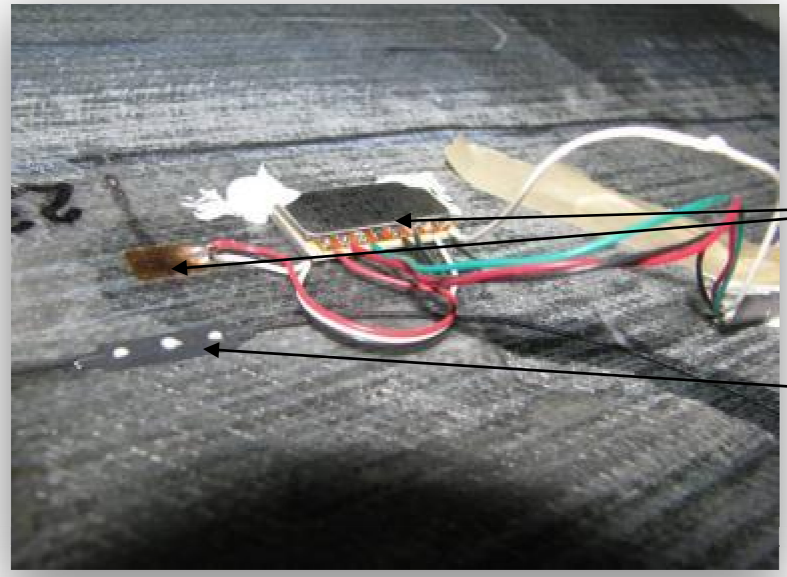
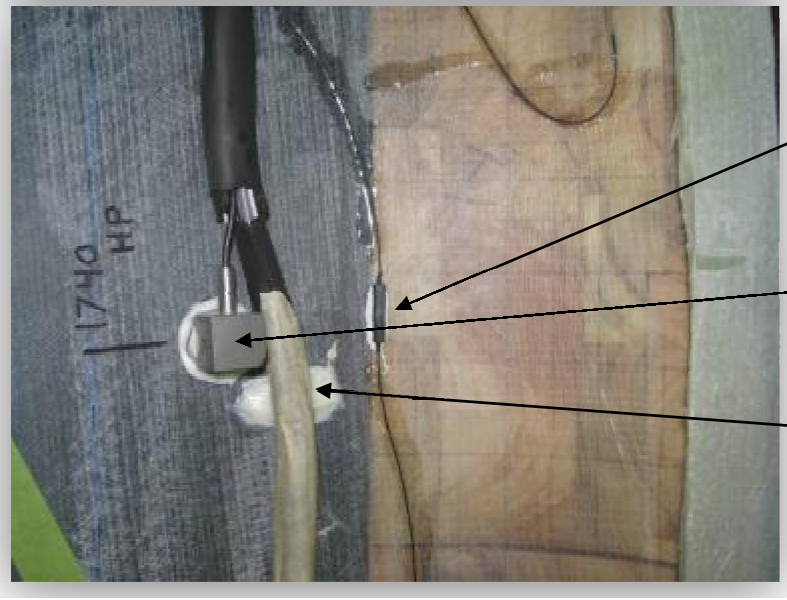
Wind Turbine Blade Monitoring: Sensor Installation Overview (TPI Composites)



Foil strain gage with completion bridge mid blade.

FBG strain gage.



Calibrated, double ended FBG temperature sensor.

Accelerometer

RTD.

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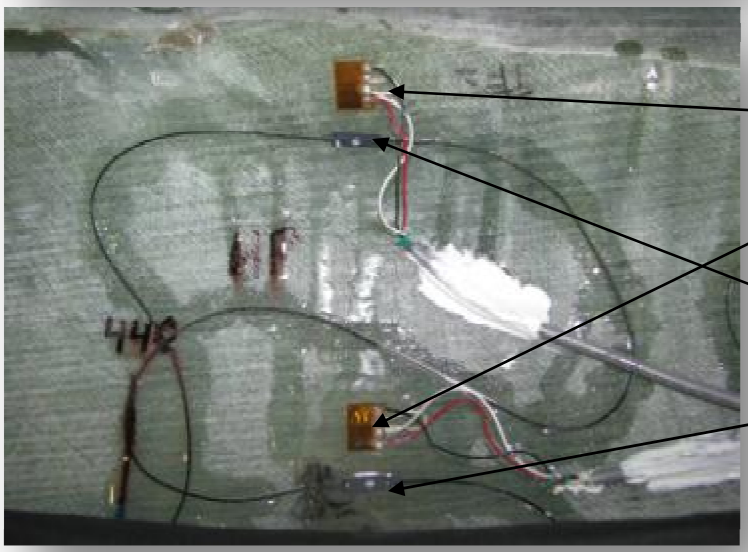
Wind Turbine Blade Monitoring: Sensor Installation Overview (TPI Composites)

Calibrated, single ended temperature sensor mounted on blade tip.



Foil strain gage.

FBG strain gage.

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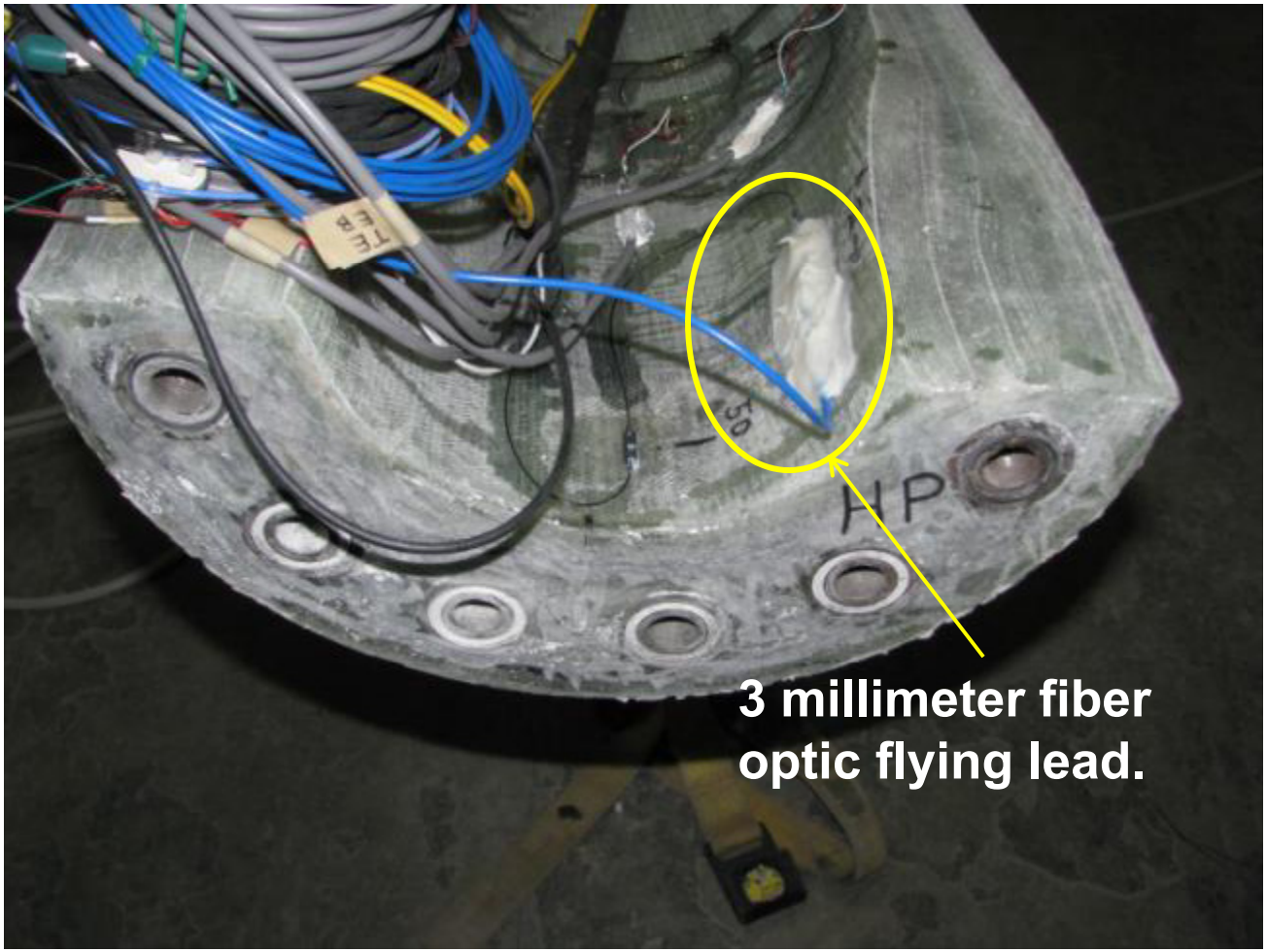
Advantages of Fiber Bragg Gratings



Large bulky wiring harnesses verses one, three millimeter cable for 15 sensors.

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Sblade Systems Verification and Calibration at Bushland, Tx. Test Facilities

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Wind Turbine Blade Monitoring: Sensor Calibration in Bushland, Texas

SBlade in static edge deflection testing position. All sensor systems utilized, calibrated and the data correlated.

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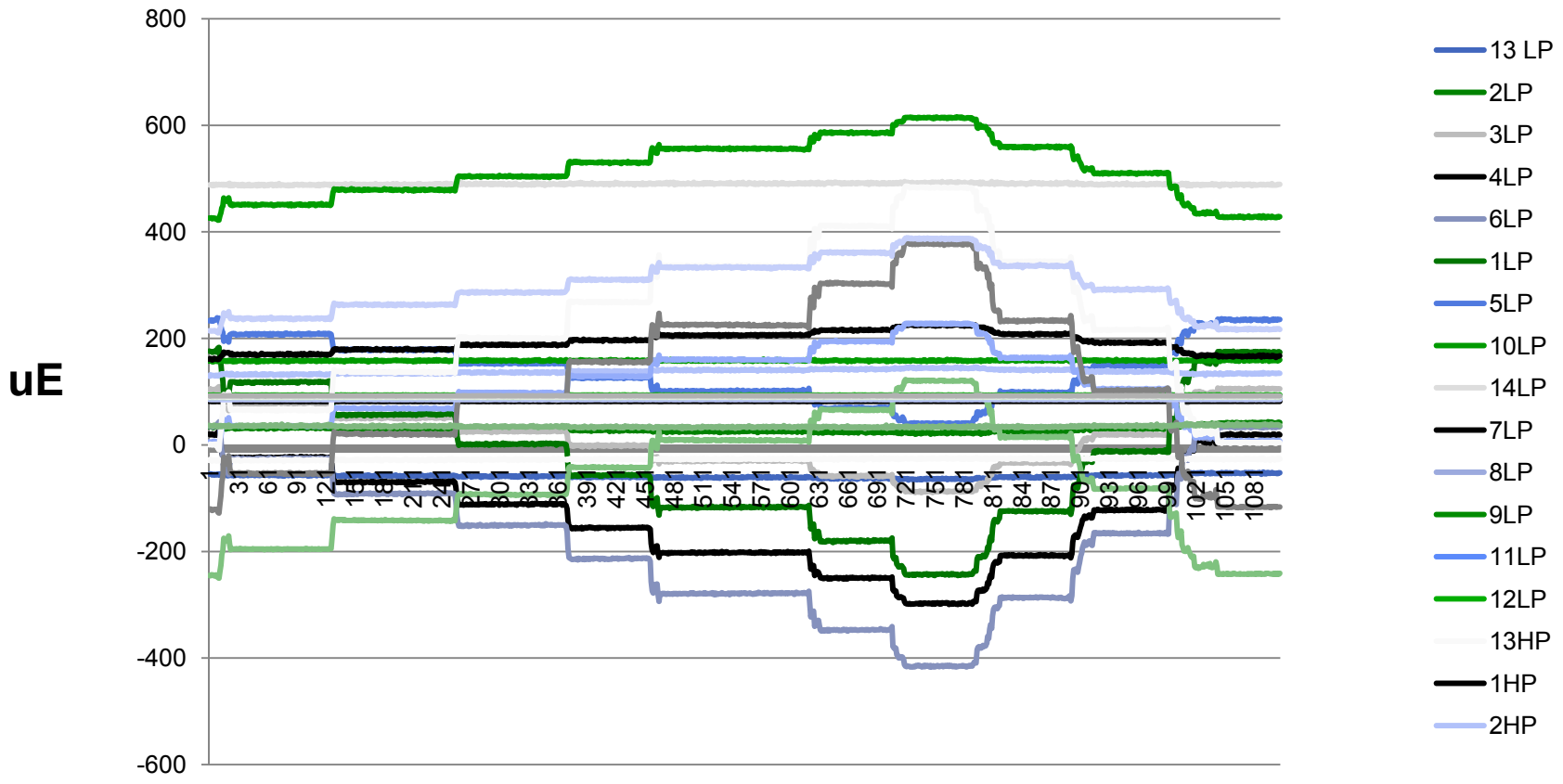
Wind Turbine Blade Monitoring: Sensor Calibration in Bushland, Texas



Sensor Load Response During Static Load Calibration

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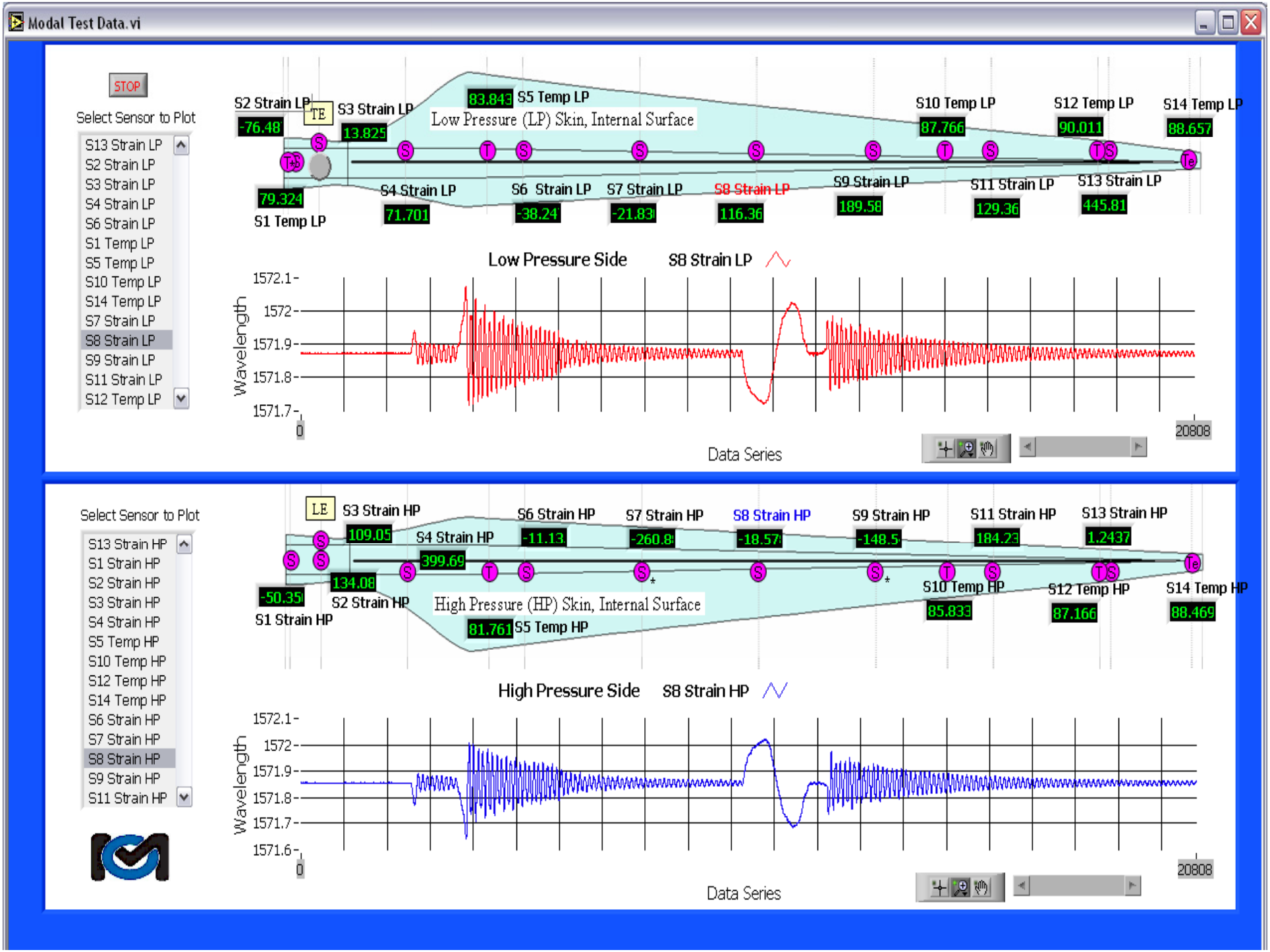
Modal Test Data.vi
STOP
Select Sensor to Plot
S13 Strain LP
S2 Strain LP
S3 Strain LP
S4 Strain LP
S6 Strain LP
S1 Temp LP
S5 Temp LP
S10 Temp LP
S14 Temp LP
S7 Strain LP
S8 Strain LP
S9 Strain LP
S11 Strain LP
S12 Temp LP
S2 Strain LP
-76.48
TE
S3 Strain LP
13.825
83.843
S5 Temp LP
Low Pressure (LP) Skin, Internal Surface
S10 Temp LP
87.766
S12 Temp LP
90.011
S14 Temp LP
88.657
79.324
S1 Temp LP
S4 Strain LP
71.701
S6 Strain LP
-38.24
S7 Strain LP
-21.83
S8 Strain LP
116.36
S9 Strain LP
189.58
S11 Strain LP
129.36
S13 Strain LP
445.81
Low Pressure Side
S8 Strain LP
Wavelength
1572.1
1572
1571.9
1571.8
1571.7
0
20808
Data Series
Select Sensor to Plot
S13 Strain HP
S1 Strain HP
S2 Strain HP
S3 Strain HP
S4 Strain HP
S5 Temp HP
S10 Temp HP
S12 Temp HP
S14 Temp HP
S6 Strain HP
S7 Strain HP
S8 Strain HP
S9 Strain HP
S11 Strain HP
LE
S3 Strain HP
109.05
S4 Strain HP
399.69
S6 Strain HP
-11.13
S7 Strain HP
-260.8
S8 Strain HP
-18.57
S9 Strain HP
-148.5
S11 Strain HP
184.23
S13 Strain HP
1.2437
-50.35
S1 Strain HP
134.08
S2 Strain HP
High Pressure (HP) Skin, Internal Surface
81.761
S5 Temp HP
S10 Temp HP
85.833
S12 Temp HP
87.166
S14 Temp HP
88.469
High Pressure Side
S8 Strain HP
Wavelength
1572.1
1572
1571.9
1571.8
1571.7
1571.6
0
20808
Data Series

Sblade Configuration, Installation and Operational Testing on Turbine

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Wind Turbine Blade Monitoring: Equipment Installation on Hub

FBG sensing system.

Data system for foil strain gages and RTDs.

Data system for accelerometers.

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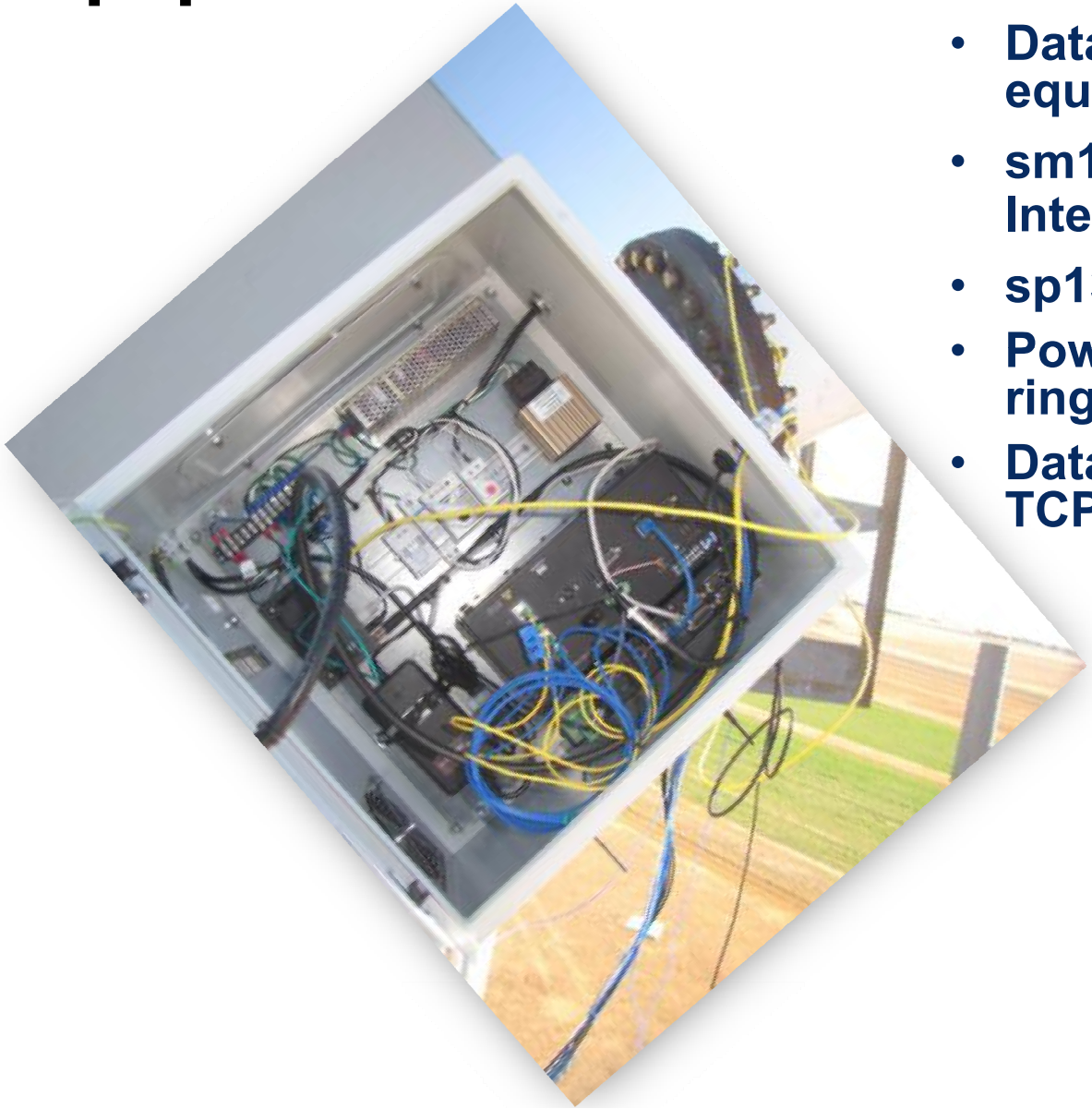
Wind Turbine Blade Monitoring: Equipment Installation on Hub



- Data acquisition and control equipment located on the hub.
- sm130-700 Optical Sensing Interrogator
- sp130 Industrial Computer
- Power is supplied thru a slip ring.
- Data is transmitted via wireless TCP\IP to control room

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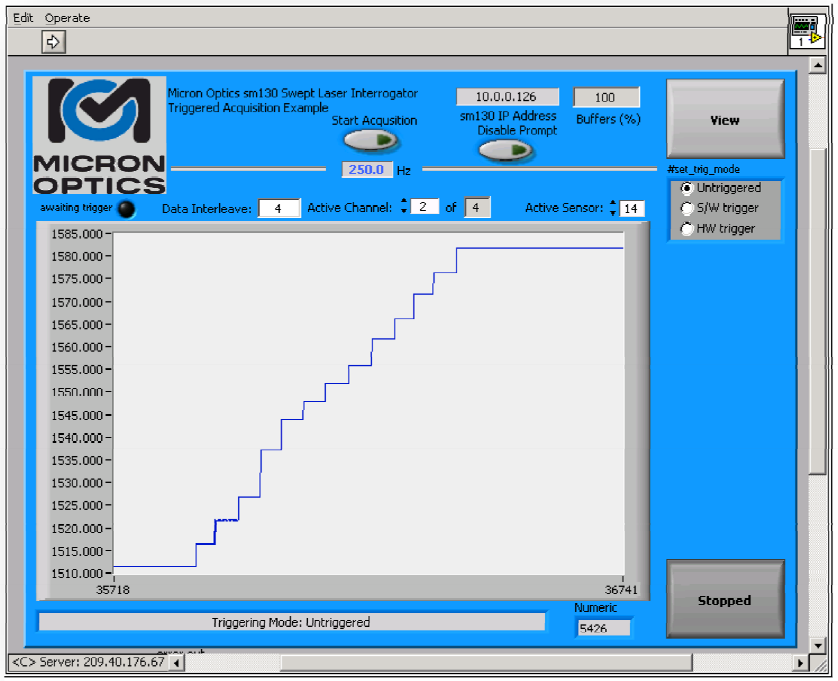
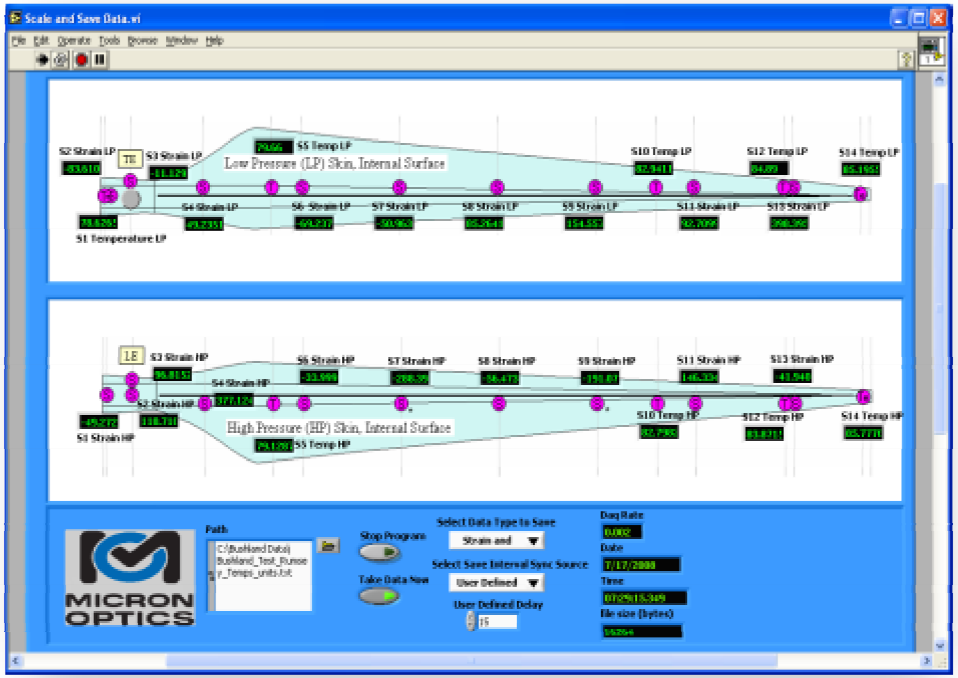
Wind Turbine Blade Monitoring: Software

Both user interfaces can be accessed thru a web browser, like IE (Internet Explorer), allowing for remote connections to the FBG blade monitoring system from any computer with access to the internet.



Graphical user interface provides for setting up the data acquisition parameters, selection of trigger source, and controlling the sm130.



Graphical user interface provides for visualization of the FBG sensor layout, scaling data, setting up of data file storage, and remote real-time monitoring.

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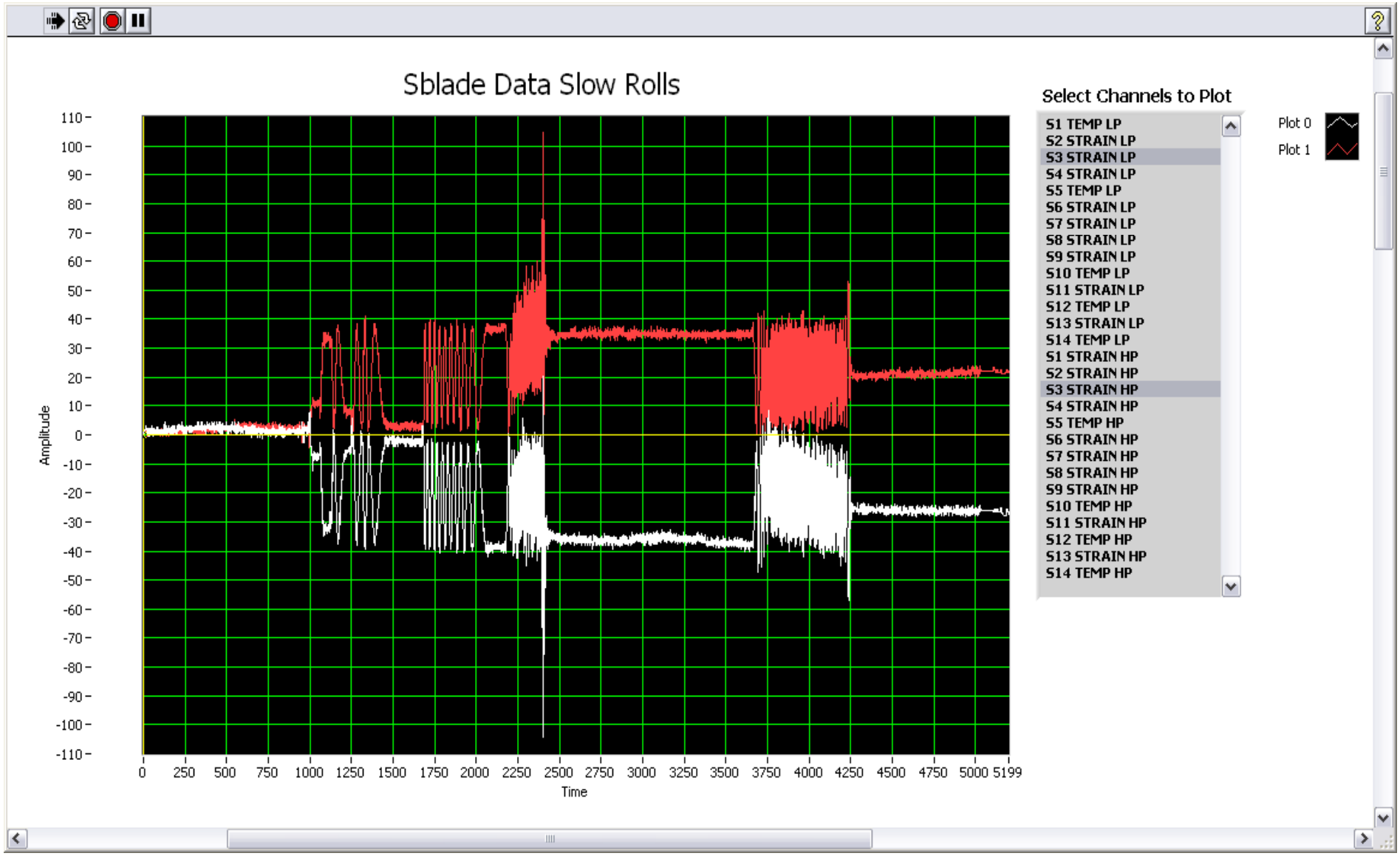
Wind Turbine Blade Monitoring: Operational Data



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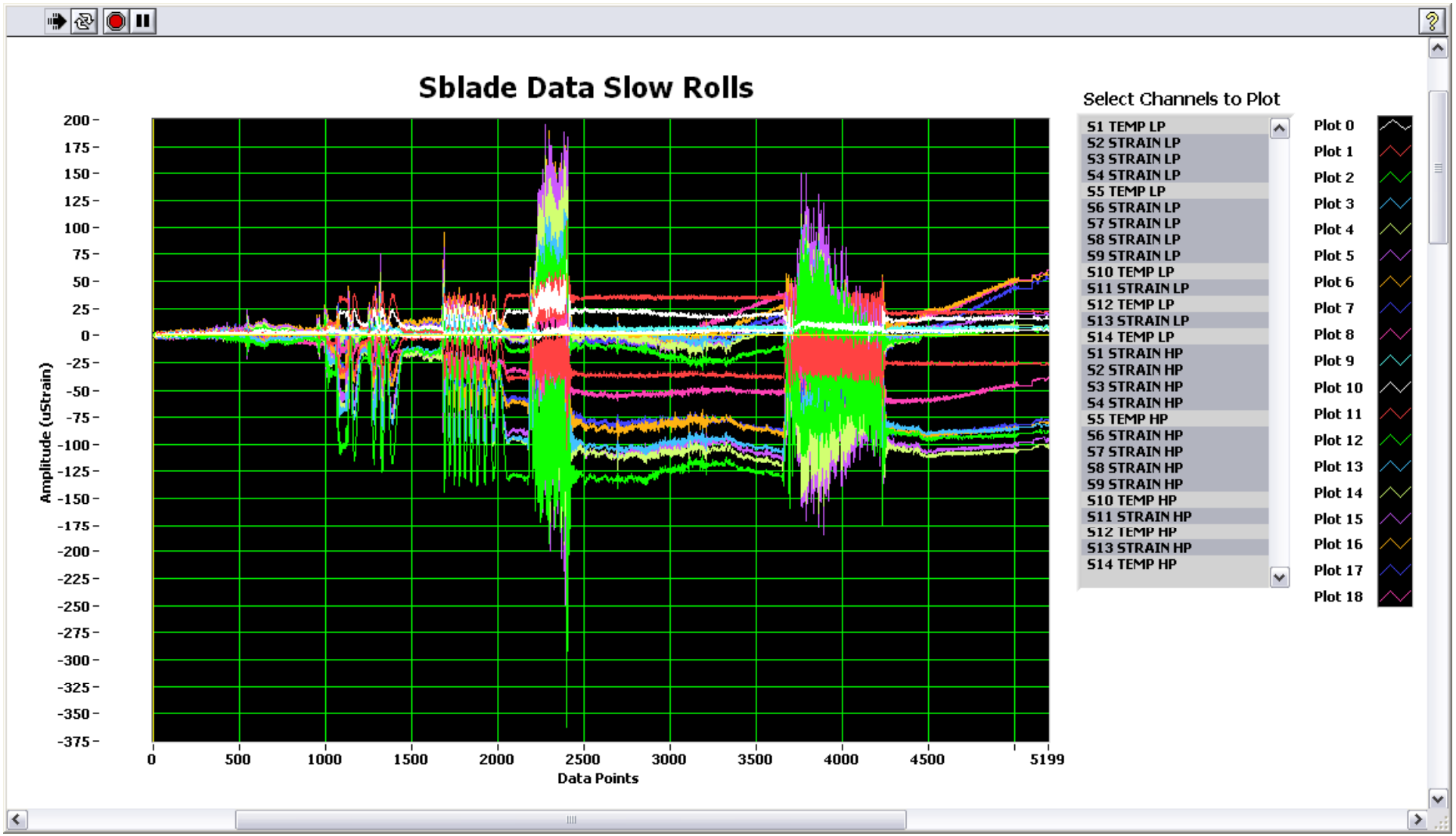
Wind Turbine Blade Monitoring: Operational Data



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Accelerated Fatigue Life Cycle Testing at National Wind Technology Center (NREL)

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Accelerated Fatigue Life Cycle Testing at National Wind Technology Center (NREL)

Sblade Test Stand at NREL Facility

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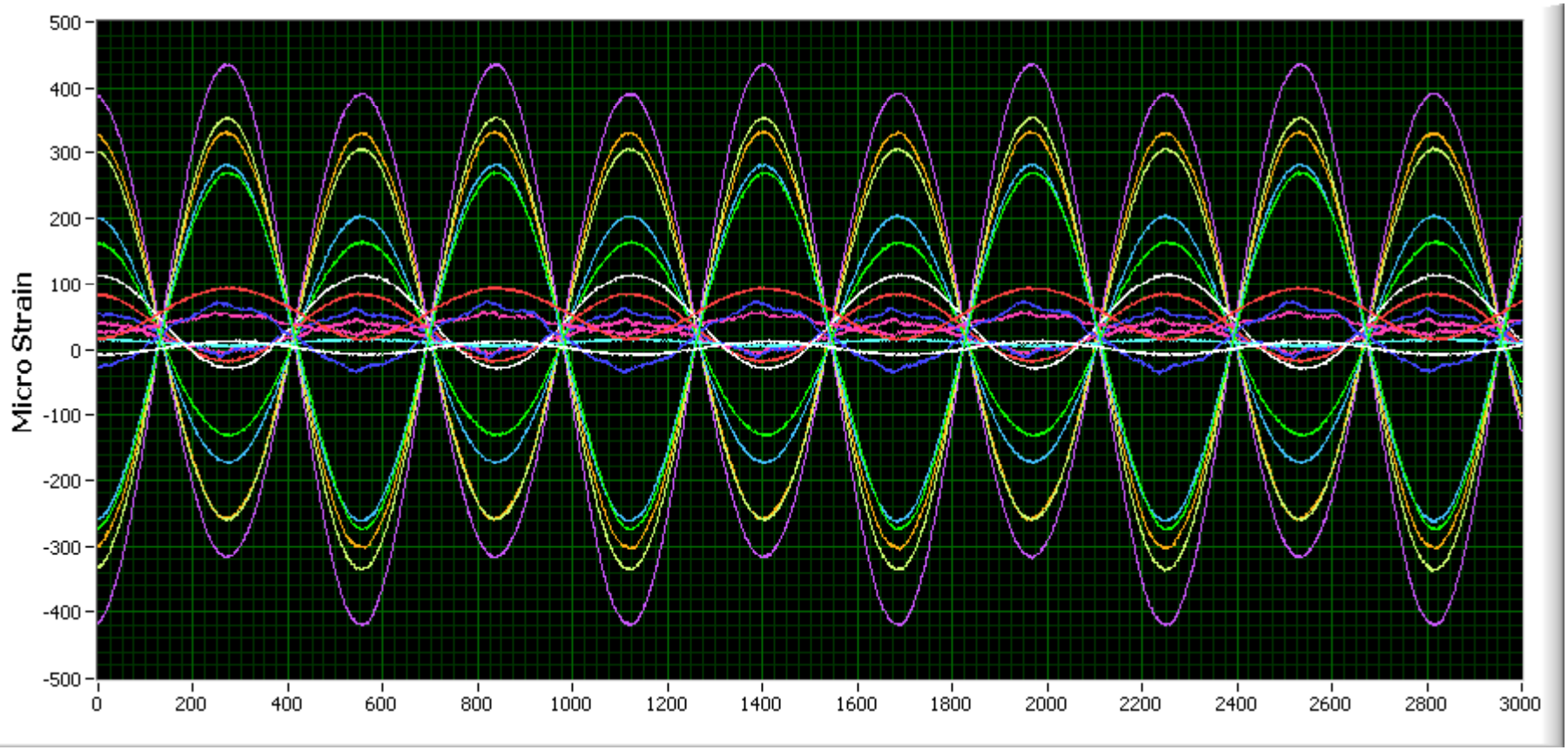
Accelerated Fatigue Life Cycle Testing at National Wind Technology Center (NREL)



Strain Response to Dynamic Loading

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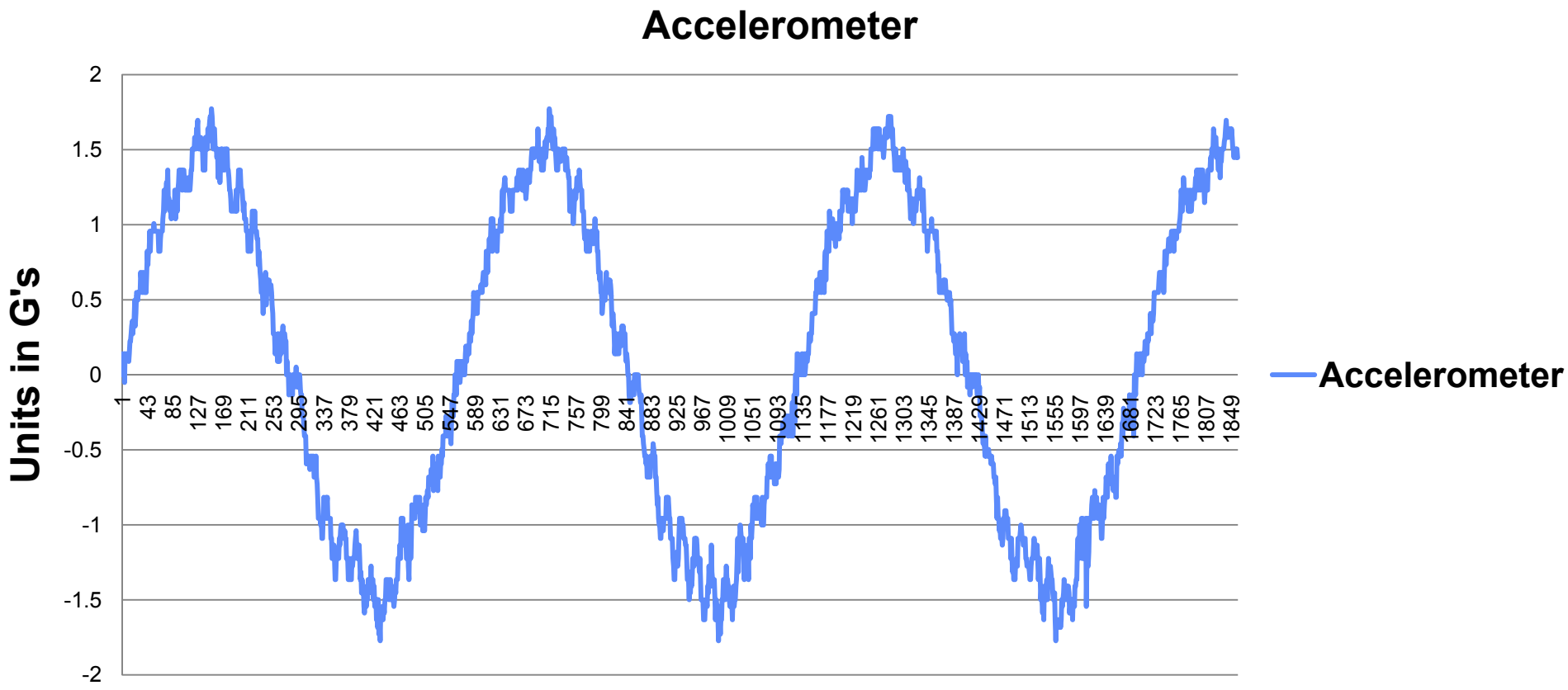
Accelerated Fatigue Life Cycle Testing at National Wind Technology Center (NREL)



Data From Accelerometer Added During Fatigue Testing

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Wind Turbine Blade Monitoring: Sblade Test Summary

- Sensors were successfully installed during the manufacturing stage. Sensor were installed in 1\3 the time the conventional strain gage installation.
- No calibration was required in the Bushland facility. Could, in fact, see the residual strains from lay up of blades at TPI, shipping to Bushland and mounting in the calibration stand.
- System provided reliable, real time data 24\7 for duration of fall\winter\spring (Including Blizzards!).
- The 1 KHz sampling rate will allow for more dynamic modeling of blade response.
- Blade and data systems removed and shipped to NREL for next phase of testing
- Blade was monitored for :
  - Static & dynamic loads
  - Temperature effects
  - Blade deflection
  - Vibrations (frequencies & modal response)
- Processing and analysis of operational data from all systems still in work

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Summary of Collaboration Between Micron Optics and Sandia National Laboratories

- This collaboration has allowed MOI to prove this technology is ready for deployment in a production environment.
- This approach and the nature of the relationship allowed for open sharing of data to potential customers and opportunity for commercial installations and opportunities.
- Enabled MOI to focus on instrument design, to address the environmental and operational conditions and to meet the industry requirements.
- Prove that the MOI system is main stream technology capable of "off the shelf" integration.
- Is a component of MOI's due diligence in providing a tested, well designed system utilizing the robustness of WDM. WDM offers the capacity and flexibility to extend basic blade strain monitoring to more complete monitoring of all critical systems.

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Summary of Collaboration Between Micron Optics and Sandia National Laboratories

- This collaboration has led to additional collaborations with the Electrical Power and Research Institute (EPRI).
- Currently utilizing our technology for investigating weld induced strains at weld joints in piping, located in power plants.
- Installation of load monitoring system, for tendons in concrete containment barriers, in nuclear power plants to begin in September 2010.

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Acknowledgements

- Mark Rumsey Sensored Blade Project Lead , Wind Energy Technology Department, Sandia National Laboratories, Albuquerque, NM 87185
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- Byron Neal, Agriculture Engineer, USDA-Agricultural Research Service, Conservation & Production Research Laboratory, Bushland, TX 79012-0010
- Jon White, PhD Candidate, PhD Research Fellow, Purdue University, Department of Mechanical Engineering, Ray W. Herrick Laboratories , West Lafayette, IN 47907-2031

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