Case Study

Using HD-FOS for Defect Detection in Wind Turbine Blades During Fabrication and Testing

The Problem Statement

The Challenge

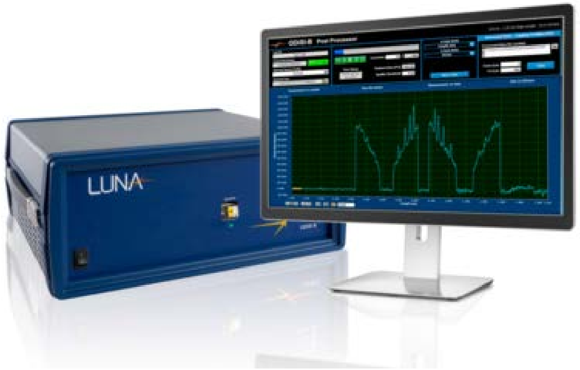
Design a “Smart” wind turbine blade that can predict when and where defects within the construction could cause potentially catastrophic failure

The sensing solution must be robust, embeddable, cost effective, provide thousands of strain sensing locations with a nearly zero weight budget

The Solution

Luna’s High Definition Distributed Fiber Sensing (HD-FOS) solution provided thousands of strain sensing points both in and on the composite blade.

In combination with Luna’s readout electronics and software, engineers performing fatigue testing were able to pin-point areas of high residual strain and predict failure many times earlier than previously possible



Overview and Background

Background

Advanced composite materials are now used exclusively in the production of wind turbine blades and increasingly in aircraft production

The design of large composite structures, subject to high loads, can be challenging. Material properties, fabrication methods and joining techniques are very different than used for traditional metals

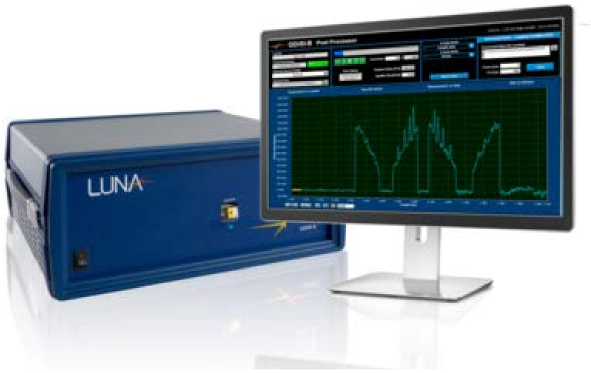
The manufacturing processes are new and can add a substantial degree of variability to a wind turbine blades (or aircraft wing's) structural performance

New methods are needed for strain measurement to characterize residual strains during layup, to detect incongruities in the composite structure and to measure strain across the joints and seams using new advanced adhesives

The Equipment

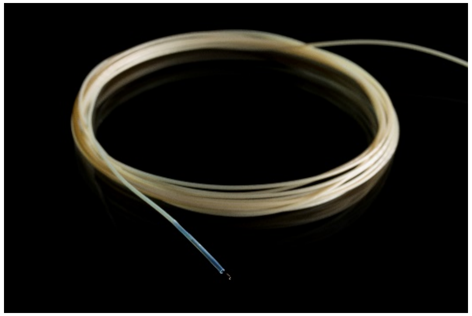
The Interrogator

An Optical Backscatter Reflectometer (OBR) was used in this test. Luna offers several models of OBR with strain and sensing capability. At right is Luna's ODiSI, an OBR optimized for strain and temperature sensing



The Sensor

The turbine blade was instrumented with HD-FOS sensors. Sensors are lightweight, minimally invasive and can be embedded within composites. The fiber is EMI immune and introduces has no electrical signal (no source of ignition)



The Switch

An (8) channel optical switch was used to serially interrogate multiple sensors. Luna offers both an (8) and (36) switch that can convert a single channel interrogator into a multi channel system

Bonding HD-FOS Sensors to the Blade Surface

Bonding the HD-FOS Sensor

Three optical fibers were bonded to the turbine blade surface using M-bond AE-10 strain gage epoxy. The bonding of fiber is similar to bonding strain gages and the same epoxies are used

Validating HD-FOS Measurements with Strain Gages

Electrical foil gages were placed along the spar cap and leading edge. The strain measurements from fiber correlated very well with the strain gages

Sensors Available in Lengths to 50 meters

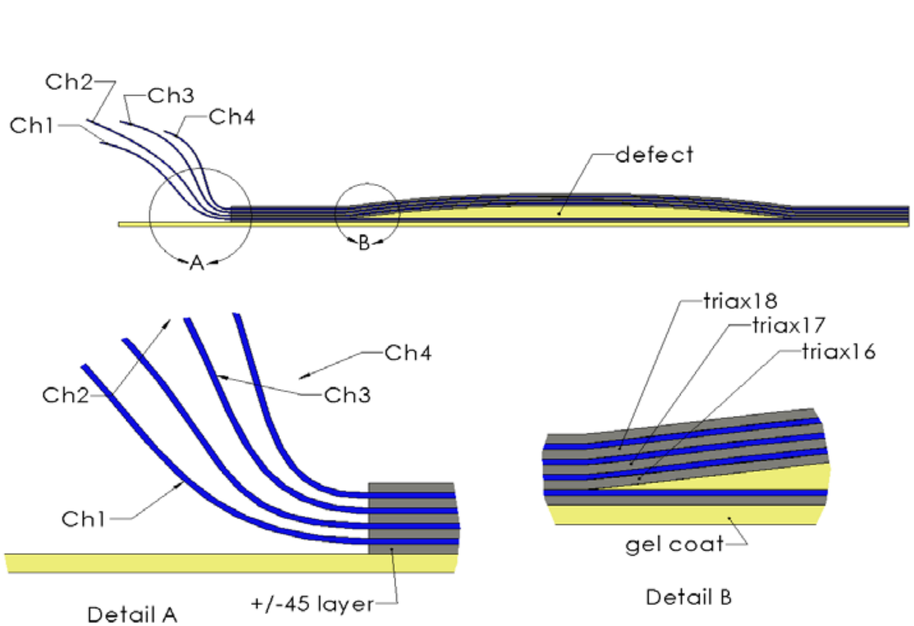
HD-FOS sensors are available in lengths up to 50 meters. The gage length and spatial resolution are configurable by software in the interrogator. In most cases the structure will not have to be re-instrumented in order to change gage location and resolution

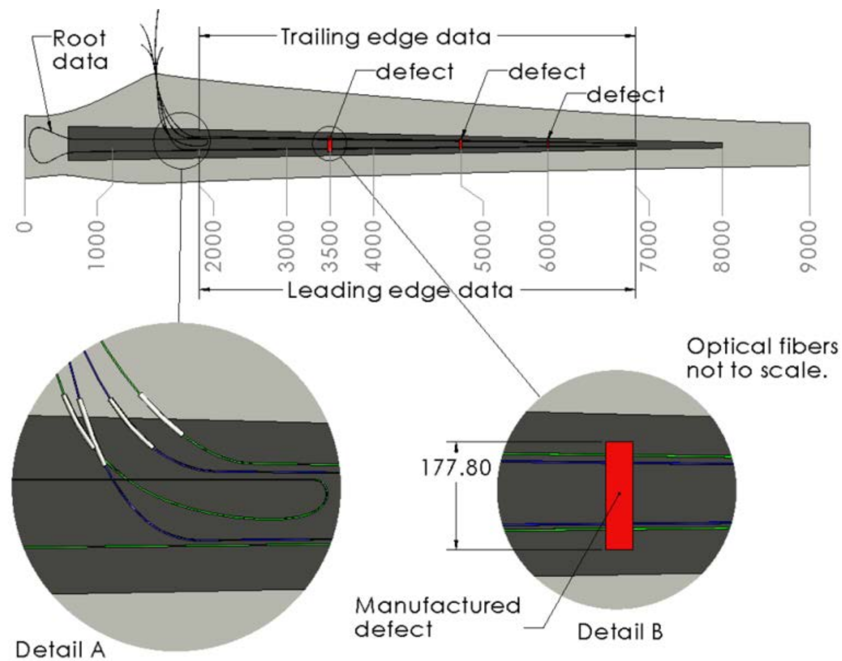
An HD-FOS sensor bonded to the surface of the turbine blade

Embedding HD-FOS in the Turbine Blade

“Smart Blade” Construction: Embedding Sensors to Capture Defects in the Manufacturing Process

- Fiber sensors were embedded in four layers of composite blade construction
- Intentional defects were introduced at three locations to simulate waviness in the composite lay up.
- The wave height of all defects was 3mm. The defect lengths were 45 mm, 30 mm and 15 mm for aspect ratios of 15, 10 and 5 respectively



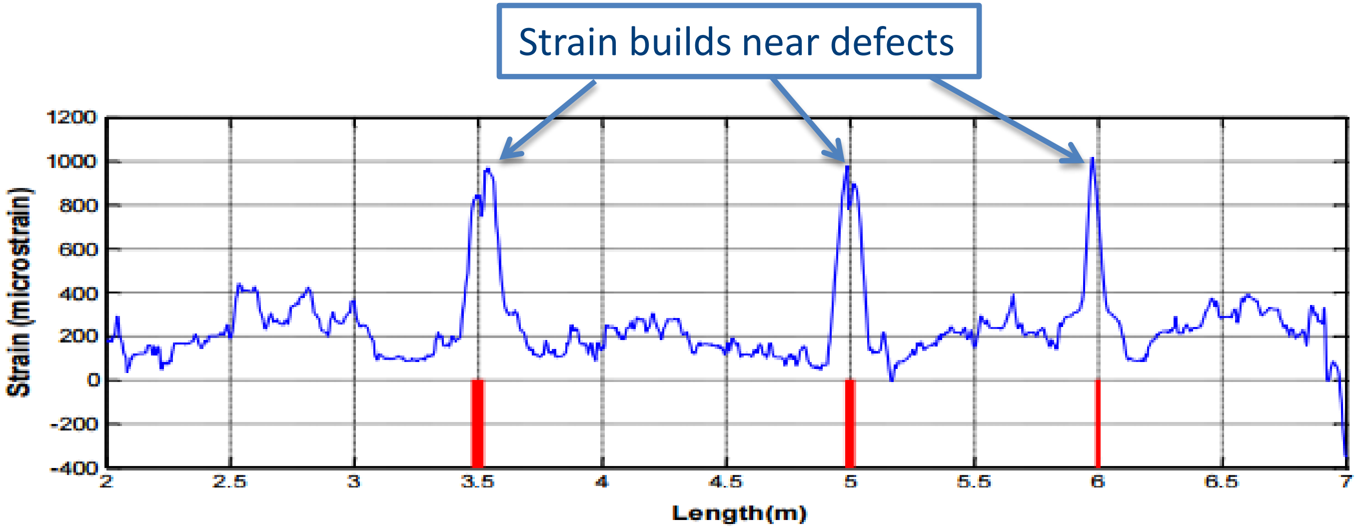


Strain Measurements from Embedded Sensor

A Low Profile and Minimally Intrusive Sensor Suitable for Embedding During Composite Fabrication

- HD-FOS strain data from embedded sensors clearly show high gradients corresponding to location of defects. The width of the strain peaks correlate with the width of the induced defect

- High resolution HD-FOS finds defects other technologies simply miss



HD-FOS Strain Measurement Under Load

Cyclical Load Testing to Failure

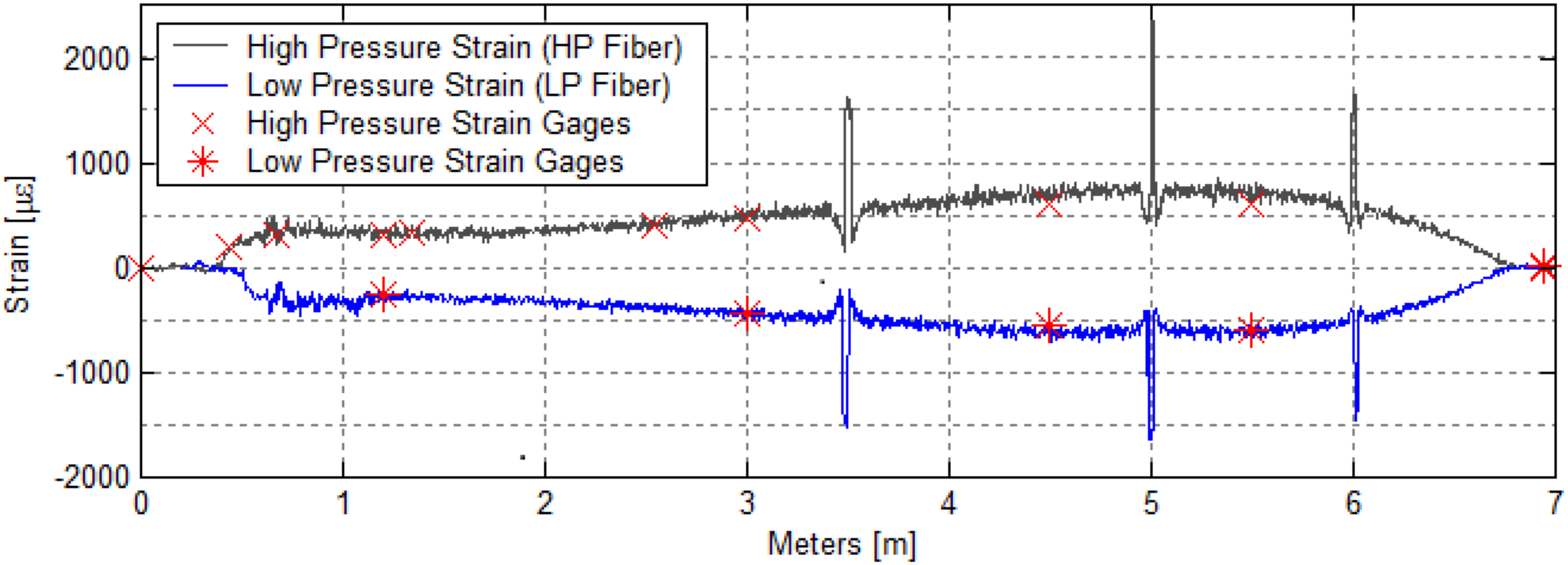
- The turbine blade was mounted in a cantilevered load test stand
- A Universal resonant excitation (UREX) system used to apply an alternating bending moment at natural frequencies
- A cyclical load applied at ±500 lbs
- At periodic cycle counts the turbine blade was statically loaded and data was taken from both the surface mounted HD-FOS sensors and point sensing strain gages

Strain Measurements During Fatigue Testing

HD-FOS Providing a Full Strain Profile Across the Blade Surface

- The data showed excellent correlation between the HD-FOS sensor and the co-located strain gages
- The location of the strain peaks correlated with the location of intentionally induced defects
- The highest strain peak, at location 5 meters along the blade length, is where the turbine blade would eventually fail during fatigue testing

Strain Measured with HD-FOS on Surface of Blade Under Load

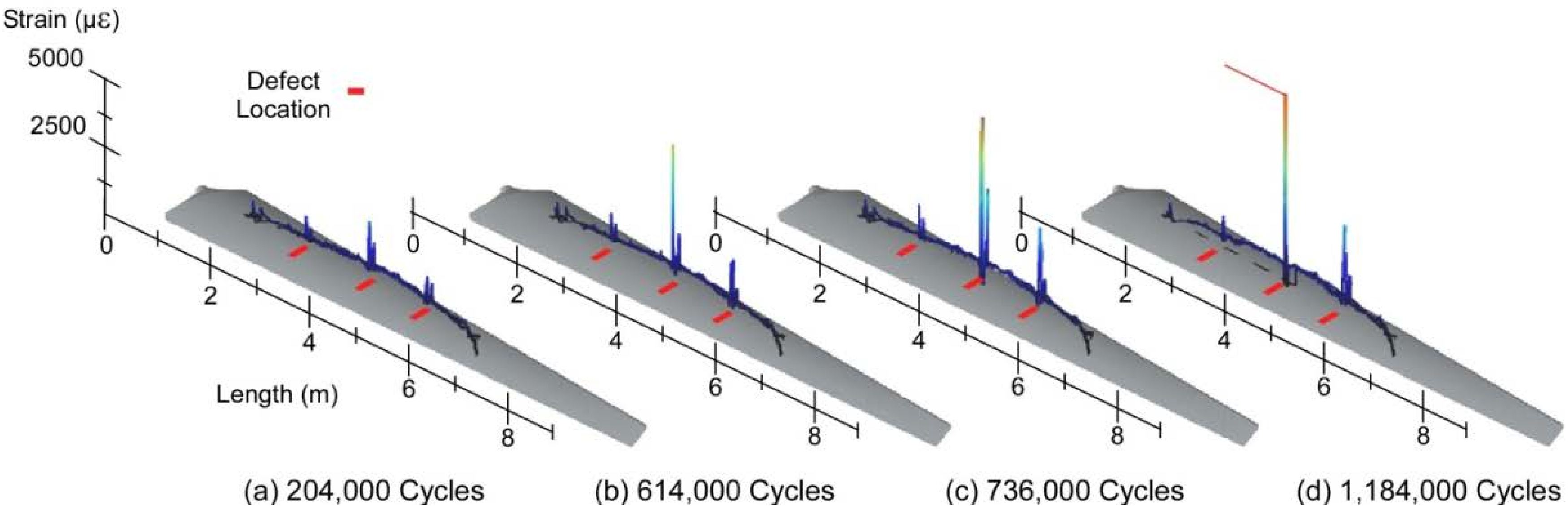


Detecting Defect Initiation & Propagation

HD-FOS Shows Propagation of Damage During the Fatigue Test

- At 614,000 cycles and prior to any visible damage, an X% increase in strain could be observed at the 5 meter induced defect point
- A visible crack eventually formed and failure occurred at this location at 1,968,000 cycles
- HD-FOS was also able to identify and track the evolution of other defects that did not ultimately result in blade failure

Strain Measurements Taken as Cycle Count Increases



Conclusions

- **<u>Unprecedented In-Situ Sensing Capability</u>** - A High Definition Fiber Optic Sensor, with its flexibility and low profile, was successfully embedded in large wind turbine blade during its fabrication without affecting the structural performance of the assembly. In testing, the HD-FOS sensor was able to reveal the location and characterization of the defects that were intentionally induced during the fabrication process

- **<u>Excellent Correlation with Traditional Strain Gages</u>** – The strain data taken with HD-FOS showed excellent correlation to the individual point sensing strain gages

- **<u>High Definition Sensing Provides a Complete Picture of Strain Gradients</u>** – The high definition sensing showed the full distribution of strain as well as the shape of the strain profile in the vicinity of the defects. The profile of the strain gradient correlated with the type of defect induced in manufacturing

- **<u>Identify Crack Initiation and Chart the Crack Propagation Leading to Failure</u>** - During fatigue testing the HD-FOS sensors indicated early in the test the eventual location of failure well before failure occurred. The sensitivity of HD-FOS was able to identify the location of the eventual failure point early in its development and track the growth of the defect leading up to failure

Thanks To…

- This work was performed in conjunction with the Department of Energy and in collaboration with the University of Massachusetts Lowell.
- Special thanks to TPI Composites, the National Wind technology Center (NWTC) and the National Renewable Energy Laboratory (NREL)

For more information visit our website www.lunainc.com

contact solutions@lunainc.com

Or call +1.540.552.5128