Rapid Flaw Detection in Wind Turbine Blade Assemblies Using Phased Array Ultrasonics

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Blade Reliability Collaborative
Advanced Manufacturing Initiative

Objectives

Create the ability for manufacturers to determine the quality of their product before it leaves the factory

- Develop, evaluate and validate the array of potential nondestructive inspection methods for the detection of flaws in composite wind turbine blades
- Plan and implement a national capability – including a physical presence and methodology – to comprehensively evaluate blade inspection techniques
- Produce optimum deployment of automated or semi-automated NDI to detect undesirable flaws in blades (time, cost, sensitivity)

FAA Airworthiness Assurance Center operated by Sandia Labs
Jackstands

Lightning Strikes

Ground Handling

Impact Damage

Bird Strikes
Program Thrusts to Improve Wind NDI

- Use of NDI reference standards to form sound basis of comparison & ensure proper equipment set-up
- Use of material property & calibration curves (attenuation, velocity)
- Human factors – adjust procedures, automate, streamline
- Improved flaw detection:
  - Advanced NDI – max signal-to-noise; image-based; sensitivity
  - Hybrid inspection approach - stack multiple methods which address array of flaw types (data fusion)
Required Relationship Between Structural Integrity and Inspection Sensitivity

Detectable Flaw Size

Allowable Flaw Size

Nondestructive Inspection

Damage Tolerance
Engineered Flaws in NDI Feedback Specimens
Shear Web & Foam Core Specimens

Shear Web/Spar with Disbonds and Delaminations

Dry fabric areas

Grease
Mold Release
Pillow Insert

Materials inserted into multiple layers
Samples of Different Flaw Types Engineered into Carbon NDI Ref Standards

Flaws were placed at varying depths and locations using a template.
Carbon NDII Reference Standards

- Pre-Preg Carbon Material
- Up to ~ 2” thick
- Quality assurance cannot visually inspect through carbon
- Greater need for NDII during manufacturing

Carbon Fiber Spar Cap Assembly

- Grease
- Paper Backing
- Carbospheres
- Pillow Inserts
- FBH
- Pull Tabs
- Flat Bottom Holes

Dimensions:
- 12”
- 36”
Completed NDI Reference Standards for Use at Blade Manufacturing Facilities

- Develop and test NDI technology
- Train inspectors and familiarize them with carbon material
- Calibrate and set up NDI equipment
- Ultrasonic flaw signal characterization
- Inspection procedure development
MAUS P-E UT with Focused Probe (1 MHz/2’’)
and Adjustable Water Path

New “Immersion” Probe Holder Allows for Adjustable Water Path

Flat Bottom Holes  Pillow Inserts

Pull Tabs

REF-STD-6-202-250-SNL-1
Pulse-Echo Inspection of Bond Joint

Adhesive Squeeze Out

Ultrasonic Transducer

A-Scan Signals

Web Squeeze Out

Web Bond Line

Spar Cap back wall

Web bond line back wall (gate set here)

Spar Cap -

Web Squeeze Out -

Web Bond Line -

1 2 3 4

1 2 4

Scan Signals
Phased Array UT Using Water Shoe

Advantages of using water shoe:

- Better/cleaner scanning signal response (less noise) which results in a better signal-to-noise ratio for flaw detection
- Better coupling - no signal dropout and easier clean-up than couplant
- Easier to deploy over scanned surface

Challenges – Requires custom contour, cannot tolerate thick foam seal at base, difficult to maintain seal when deploying vertically
Inspections must address all field deployment issues:

- Vertical and horizontal inspection surfaces
- Hand scan vs. attachable scanner
- Signal coupling – water flow, air bubbles
- Wide range of thicknesses (gate adjustments)
- Quantitative information
- Ease and rate of inspection
NDI Ref Std – Adhesive Step Wedge

Bottom View

Side View - Adhesive Area

UT C-Scan Using Time of Flight

(1.01) (1.07) (1.18) (1.26) (1.37) (1.48)

Thin  Thick

Thin  Thick

UT C-Scan Using Time of Flight
Goal: Develop and assess methods to rapidly inspect/quantify bond line thickness

Adhesive Wedge NDI Reference Standard
Adhesive Thickness Measurements with Phased Array UT

Omniscan UT Device 1.5L16 (1.5 MHZ) Phased Array Water Box REF-STD-F6-086-TW-A

Use of Dual Gates to Quantify Bond Thickness

Amplitude C-Scan Produced by Green (B) Gate Set Across Proper Bond Line Thickness

Digital Thickness Reading Measuring The Adhesive Area Only (diff between Gate A and Gate B)

Floating Backwall Signal

Interface Signal

Good Bond Line Thickness

Anomalies in Bond Line Thickness
Design of Delay Lines to Avoid Signal Interference

Water Box Signal Analysis - 25mm compared to 40mm; Moves harmonic return signal outside area of interest.

In the images:
- Backwall Fiberglass
- Signal Located within Front Surface Signal Harmonic
- Front Surface Signal Harmonic
- 25mm Delay
- 40mm Delay

Sandia has focused on a sealed couplant box that:
- Adjusts to slight curvature in surfaces
- Eliminates water flow to open box
- Maximizes signal strength
- Accommodates necessary standoffs for signal clarity
- Easily saves scanned images for reference using a wheel encoder
Goal is to develop a sealed water path that produces clear signal through a wide range of thicknesses (up to 2.5 inches) and curvatures.
Spar Cap and Shear Web
NDI Feedback Specimen No. 6

REF-STD-6-202-250-SNL-1
Omniscan Phased Array with 1.5 MHz & 40 mm Water Box

Water Boxes
25mm 40mm

Backwall Signal From Spar Region Only

Backwall Signal From Adhesive Bondline at Shear Web

Adhesive Bondline at Shear Web Point 2 (67 mm)

25mm 40mm Water Boxes

Backwall of Spar Point 1 (50 mm)
Sandia has requested increase of pulse width to 1 micro second, which is half of 0.5MHz wave length.
Ultrasonic Characterization of Solid Laminates and Adhesive - Porosity

Goal: work with wind blade manufacturing sites to accumulate a series of porosity measurements, along with corresponding UT attenuation and velocity and UT property measurements to generate calibration curves for use in production QA.

Porosity Measurements - Optical Microscopy and Ignition Loss of Fiber/Resin

Multi-Specimen Gain (Attenuation) Characterization

NDI Determination of Porosity Levels
How could quality assurance curves be used by inspectors to determine the quality of a blade?

Response calibration curve that can be used for QA – family of curves could produce an envelope of acceptable attenuation levels

Porosity (%) vs. Attenuation (dB) diagram:
- **GOOD** region
- **BAD** region
- Specified by manufacturer
- Checked by Inspector

Specified thicknesses:
- t = 0.5"
- t = 0.75"
- t = 1.0"
- t = 1.25"

Porosity (%) values:
- 2, 4, 6, 8, 10

Attenuation (dB) values:
- 10, 20, 30

Data source: Sandia National Laboratories
Wind Blade Probability of Detection Experiment

- Representative blade specimens; realistic flaw types
- Blind experiment: type, location and size of flaws are not known by inspector
- Statistically relevant flaw distribution – Probability of Detection (POD)
- Used to analytically determine the performance of NDI techniques – hits, misses, false-calls, flaw sizing

Spar Caps & Shear Web

Box Spar & Shear Webs

Review Committee

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Sandia National Laboratories
• Develop array of inspection tools to comprehensively assess blade integrity (determine needs, challenges, and NDI limitations)

• Achieve this while considering time, cost, & sensitivity issues (minimize production & maintenance costs)

• Develop NDI solutions in concert with related studies: effects of defects, field surveys, analysis, certification, standards

• Identification of impediments to be overcome and develop NDI ref stds

• NDI investigation has produced promising results thus far & may lead to hybrid approach with multiple NDI tools

• NDI to extend blade design life (??)