# Barely visible impact damage detection in a composite turbine blade using 3D Scanning Laser Vibrometery

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## 1. Introduction

Fossil fuel reserves are ever decreasing whilst the global demand for electrical power is increasing. These trends combined with the need to develop greener and more sustainable power sources has seen an increase in wind power in recent years with now nearly 6000 offshore and on-shore wind turbines in the UK alone [1]. In order to ensure the functionality of the turbine, it is beneficial to monitor the structural health of key components such as the blades in order to detect and monitor any damage. This would enable maintenance operations to be carried out when required reducing the downtime of the turbine, maintenance costs and increasing overall energy production [2]. This is particularly advantageous for offshore turbines where access is difficult.

Acousto-ultrasonic induced Lamb waves have been used for detecting damage in composite structures for many years [3]. The principle works by exciting a piezoelectric transducer mounted to the structure's surface which induces a Lamb wave that is then detected by another transducer mounted at a different location on the structure. If damage occurs within the field between the two sensors, the signal propagation is altered thus resulting in a quantifiable difference in the signal received. This technique has proven to be effective in the detection of impact damage [4].

Laser vibrometery is a useful tool for understanding Lamb wave propagation and their interaction with damage [3]. By understanding and characterizing this interaction with impact damage it is possible to improve damage detection techniques and optimize sensor locations.

## 2. Experimental Procedure

The objective of this research was to develop a physical understanding of the propagation of Lamb waves through complex composite structures and their interaction with induced impact damage using 3D scanning laser vibrometery. The work presented here forms part of a much wider study on damage detection and location on complex composite structures.

The wind turbine blade used for this study was a 1.8m composite blade of unknown construction shown in Figure 1. An area on the front face of the blade region between the root and tip was selected as the area of investigation as the curvature of this section of the blade would ensure that quantifiable impact damage could be induced.

Figure 1: The Composite Wind Turbine Blade used for this study

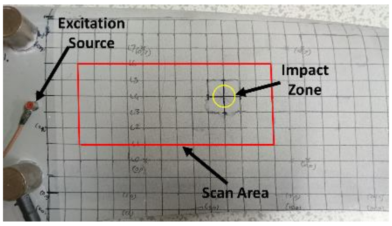

Figure 2: Vibrometer scan area and impact zone.

A PANCOM Pico-Z transducer was bonded to face of the blade 115mm from the designated impact source. This distance was chosen to allow the Lamb wave modes to sufficiently form before interacting with the damage. The transducer was excited with a 150V 5-cycle sine burst generated by Physical Acoustics WaveGen function generator software connected to Physical Acoustics µdisp/NB-8 hardware. Studies that have been performed alongside this research had indicated that frequencies below 300kHz significantly interacted with impact damage in composites. Three frequencies were selected for this experiment; 100 kHz, 200 kHz and 300 kHz. A 10 V peak-to-peak wave was also generated and used as a reference signal for triggering the acquisition of the vibrometer. A repetitive trigger rate of 20 Hz was used as this gave sufficient time for the induced wave energy to fully dissipate before taking the next measurement.

A purpose built steel stanchion was used for mounting the turbine blade while being scanned by the laser vibrometer. This allowed for blade to be removed for impacting and replaced in the same position relative to the vibrometer laser heads.

The vibrometer used for this experiment was the Polytec PSV-500-3D-M. This vibrometer uses three laser heads to measure each scan point. The measurements recorded by each laser head can then be used to calculate using trigonometry both the in-plane and out-of-plane modes. Due to taking measurements from three heads it is less important for the laser heads to be perpendicular to the structure under test with a 3D scanning system compared to that of a 1D system.

A scan area of 120mm x 50mm consisting of 2514 measurement points as shown in Figur was chosen as the area of investigation.

The turbine blade was scanned with the vibrometer prior to impact. The blade was then subjected to a 10J impact using an Instron 9250HV impact test machine. After the impact, the barely visible impact damage (BVID) was measured using a Taylor-Hobson Talysurf surface profilometer to quantify the scale of the damage induced prior to being rescanned with the vibrometer.

## 3. Results and Discussion

The results from the 2D surface profile measurement presented in Figure 3 show that induced impact caused BVID of 73µm deep. BVID is typically classified as impact damage that causes an indentation in the region of 0.25-0.5mm. This impact damage therefore is substantially shallower than what is normally considered as BVID.

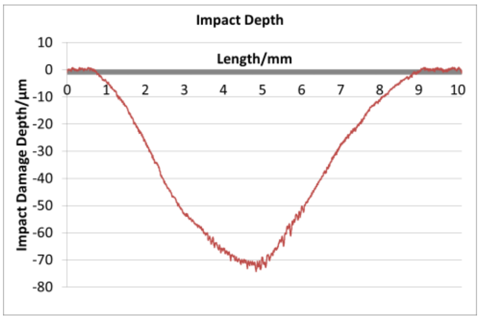

Figure 3: Surface profile measurement of the resulting BVID after the impact damage

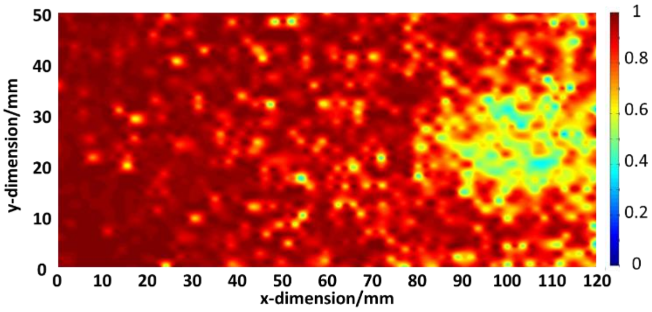

Figure 5: 200kHz Out-of-plane cross correlation plot. Note the low correlation in the region around the impact area

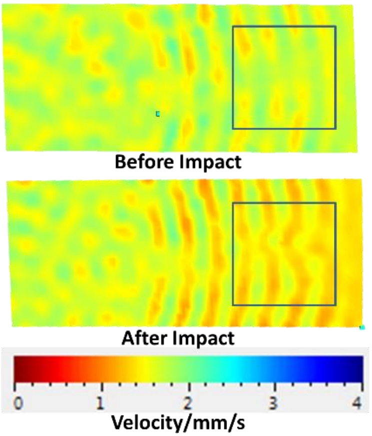

Figure 4: 3D velocity result plots of the turbine blade before and after impact when excited at 100kHz

The results plots presented in Figure 4 show the 3D measurement plots of the 100kHz Lamb wave from the vibrometer before and after impact. Comparing the two plots, the induced lamb wave clearly interacts with the damage causing a change to the shape of the wave front.

As the measurement points for both scans were in nominally identical places it was possible to make a direct comparison of the measured waves. A cross-correlation technique was used to compare the similarity of the measured waveforms at each point. It was then possible to plot a graphical representation of these cross-correlation values giving visual identification to the location of the damage. The out-of-plane cross-correlation plot for the 200kHz measurements is shown in Figure 5. Identifying the region of low correlation enables the damage to be located as well as highlighting a suitable region for the placement of a sensing transducer.

## 4. Conclusions

This study reinforces the use of acousto-ultrasonics for the detection of BVID. It has highlighted that it is possible to detect shallow BVID in complex composite structures such as a wind turbine blade. The use of 3D scanning laser vibrometry has demonstrated how Lamb waves interact with BVID in complex composite structures furthering the understanding of damage detection. The cross-correlation analysis has not only identified the presence and location of damage but has also identified that in an active sensor network, the location of the receiving sensor is critical in successfully identifying the presence of damage.

## 5. References

1. RenewableUK. *UK Wind Database*. 2014 [cited 2014 4/12/2014]; Available from: http://www.renewableuk.com/en/renewable-energy/wind-energy/uk-wind-energy-database/index.cfm.
2. Jiabiao, R., et al., *Wind turbine blade damage detection using an active sensing approach.* Smart Materials and Structures, 2014. **23**(10): p. 105005.
3. Staszewski, W.J., et al., *Structural health monitoring using scanning laser vibrometry: I. Lamb wave sensing.* Smart Materials and Structures, 2004. **13**(2): p. 251.
4. Banerjee, S., et al., *Autonomous impact damage monitoring in a stiffened composite panel.* Journal of Intelligent Material Systems and Structures, 2007. **18**(6): p. 623-633.