# Quantitative Damage Assessment of Hybrid Composite Wind Turbine Blades by Energy Based Acoustic Emission Source Location

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# QUANTITATIVE DAMAGE ASSESSMENT OF HYBRID COMPOSITE WIND TURBINE BLADES BY ENERGY BASED ACOUSTIC EMISSION SOURCE LOCATION

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## ABSTRACT

Acoustic emission technology was applied to assess the damage in the wind turbine blade. It was tried to apply a new source location method, which has a developed algorithm ourself with energy contour mapping concept. Firstly, we acquired energy based contour map database for tested blade section. And then, we measured the activities and the intensity of each arrival signals for several types of damage sources. That is, this study aims to locate and evaluate the damages such as internal damages or foreign impacts etc.. In this study, we focused to enhance a source location method with energy contour map which is developed already, and to develop a new damage index for more clear damage identification. For damage indexing, we found the correlation between corresponding energy and distance from source. Then, after calculating the location of damage source, we can doing more quantitative assessment using pre-acquired damage indexing. Consequently, the applicability of new source location method was confirmed by comparison of the result of source location and experimental damage location. From several experimental results, new suggested method of damage index identification showed very good performance for assessment of damages in the hybrid composites structures.

***KEYWORDS :*** *acoustic emission, quantitative damage assessment, source location, wind turbine blade, hybrid composites*

## INTRODUCTION

Structural health management is one of the major issues for monitoring and assessing of the integrity of large structures like a huge wind turbine blade. There are two key interested things that can contribute as non-destructive technology point of view. One is how to detect defects inside more exactly after manufacturing of each component. The other one is how to monitor its integrity during operation. So, it is very important to detect and locate the damages early in the structures, since it can tell a symptom of damage propagation before catastrophic failure. Acoustic emission (AE) is known as a powerful nondestructive tool to detect any further growth of preexisting cracks or to characterize failure mechanisms. Recently, this kind of technique, that is an in-situ monitoring of integrity of materials or structures, becomes increasingly popular for monitoring the conditions of large structures like a wind turbine blade. Therefore, it is required to find early damage progress before catastrophic failure through a continuous monitoring and periodic inspection.

In order to harvest more energy with higher efficiency and cost-effective considerations, the size of the wind turbine blade has increased over the years. Usually the size of blade is typically about 25 m for 750 kW and about 45 m for 2-3 MW in their length. As wind turbine blades increase in size, there is an increasing need to monitor the integrity of the structures [1,2]. In addition, the technology for structural health monitoring (SHM) may allow the use of lighter blades that would provide higher performance with less conservative margins of safety [3].

The wind turbine blades usually use several composite materials such as glass fiber reinforced plastic (GFRP), polyvinyl chloride (PVC) and balsawood which ensure weight vs. strength ratio. And also they have different thickness in blade root and tip because of weight distribution and aerodynamic shape for efficiency of power generation. So, more appropriate non-destructive testing (NDT) method for evaluating the integrity of this kind of composite material structures is recently required. There are several structural damage factors for wind turbine blade such as incomplete permeation of resin in manufacturing process, adhesive missing in bonding process and impact damages during transportation and installation [4]. In addition, there are many foreign factors to affect integrity of wind turbine blade. Typically it is a delamination of composites by sudden wind gust, cracking by foreign objects impact and natural disaster such as lightening, hail and typhoon during normal operation [5,6].

Finally, we also need to evaluate the degree of damages as well as locating the damage sources. Because the owner of  facilities have to make a decision how to repair or to monitor for the damage-located structures. So, it is very important to understand the characteristics of damages for more clear damage identification. Some intelligent fault diagnosis methods are studied such as novelty detection techniques. These methods are a statistical outlier analysis which allows a diagnosis of deviation from normality, an Auto-Associative Neural Network (AANN) and an Artificial Neural Network (ANN) classification technique. Vibration responses combined with a novelty approach provide a robust statistical method for low-level structural damage detection [7]. As an signal analysis method, acoustic emission signal parameters were used to identify and characterize the various damage mechanisms in stressed glass fiber reinforced polymer composite. The data from acoustic emission are used as inputs in a Kohonen self-organizing map which automatically separate the acoustic emission signals, enabling a correlation with the failure mode. These results open perspectives for real-time damage recognition in complex composite materials [8]. And also, some procedure was proposed for damage identification and discrimination for composite materials based on acoustic emission signals clustering using artificial neural networks. They developed an unsupervised methodology based on the self-organizing map of Kohonen. Finally, damage sequence has been identified from the modal nature of the AE waves. [9]

In this study, it was tried to apply a new acoustic emission source location method which has a developed algorithm ourself, and also to identify the degree of damage in the wind turbine blade.

## 1 CONTOUR MAP BASED SOURCE LOCATION AND DAMAGE INDEXING

Usually the limitation of conventional AE source location method using arrival time difference is strongly revealed by the dependence of wave speed in the corresponding material of tested structures, especially inhomogeneous material or heterogeneous structures. In case of the wind turbine blade, it is very hard to measure conventional acoustic emission signal in normal ultrasonic frequency ranges, because this kinds of dissimilar composite materials have high attenuation property and very thick geometry in skin thickness.

Therefore new proposed source location method should be less affected by the wave speed in these kinds of composite blades. That is, the measurement of energy distribution in the composite materials is better than time arrival method in its reproducibility point of view. Also it will be better to install minimum number of sensors on the structures to be covered. In order to satisfy these conditions, we have developed a new source location algorithm of acoustic emission signal energy based contour map [10,11].

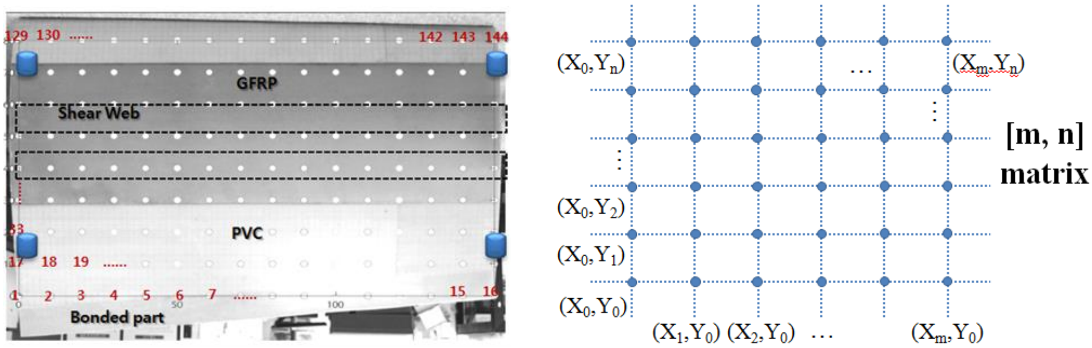



Figure 1: Input source generation process in the energy mapping source location method

Figure 1 shows the input source generation process which indicates the position of sensor and input data point to be tested. Usually one acoustic emission sensors are needed to get one contour maps for interesting area of blade. In case of the Figure 1, total four sensors and 144 test points were used to calculate AE signal intensity and construct a contour map of blade to be tested. After conducting the several steps of signal processing, database contour map was completed for each sensor as shown in Figure 2. This contour map indicates a pattern of signal attenuation corresponding to the position of sensor and input source [11].

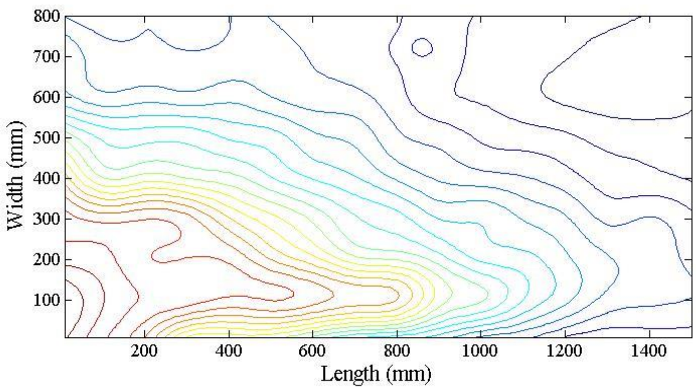



Figure 2: Contour map for each sensor

Firstly, we acquired energy based contour map database for tested blade section. And then, we measured the activities and the intensity of each arrival signals for several types of damage sources. That is, after locating a damage source, the evaluation for damage type was carried out through damage indexing procedure. In this study, we focused to develop a new damage index for more clear damage identification as well as enhancing a source location method with energy contour map which is developed already. For damage indexing, we found the correlation between corresponding energy and distance from source. Then, after calculating the location of damage source, we can doing more quantitative assessment using pre-acquired damage indexing.

## 2 EXPERIMENTS

In order to assess the damages in the wind turbine blade, we have used a part of full scale blade of 3 MW in capacity. As shown in Fig. 3, this blade was specially cutted for experiments, which is 2,000 mm long in length and 1,500 mm in width. They consist of two skin plate and two vertical shear web in the middle of blade. This blade skins and shear web is made of glass fiber reinforced plastic (GFRP) and balsawood respectively.

In this experiment, six R6I type sensors (PAC, USA) which have 60 kHz resonant frequency ranges were used, and this integrated type sensor includes a pre-amplifier inside. These six acoustic emission sensors were attached on the outside skin of blade using couplant. The position of attached sensors is shown in Figure 3. We have used two measurement system of commercial acoustic emission equipment and self-assembled high-speed digitizer. MicroSAMOS AE system (PAC, USA) was used for AE data acquisition and analysis, and also 8 channel high speed digitizer was used to acquire raw data signal for applying of new proposed source location algorithm.

A series of pre-database acquisition procedure was carried out before installation of blade for testing. In order to draw the contour map of blade to be tested, each different input sources such as a Nd-Yag pulse laser source (Fig. 4), a pencil lead break (PLB), a commercial ball-drop type impact source Equo-tip-D/-G type tester, were used for elastic wave source generation.


Figure 3: Wind turbine test specimen

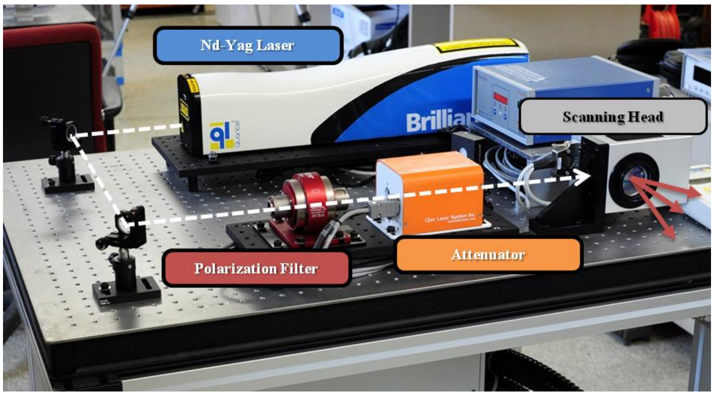
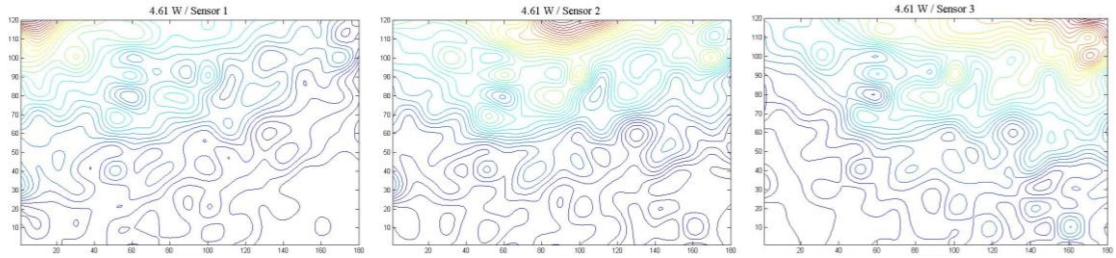


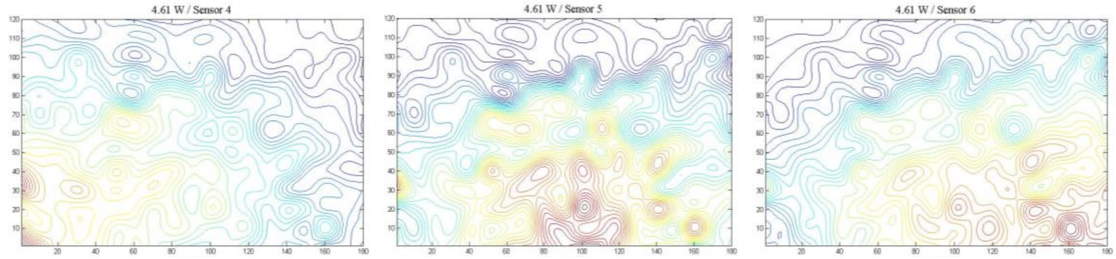

Figure 4: Nd-Yag pulse laser scanning system for source generation

## 3 RESULTS AND DISCUSSIONS

Fig. 5 shows their own contour map for each sensor, which was measured from the input source of nine scales of pulse laser representatively. The matrix of the database consisted of the energy values which are propagated from each source input to receiving sensor. In this figure, the contour map of six sensors shows only for input pulse laser of 4.6 W.




(a) sensor 1 (b) sensor 2 (c) sensor 3

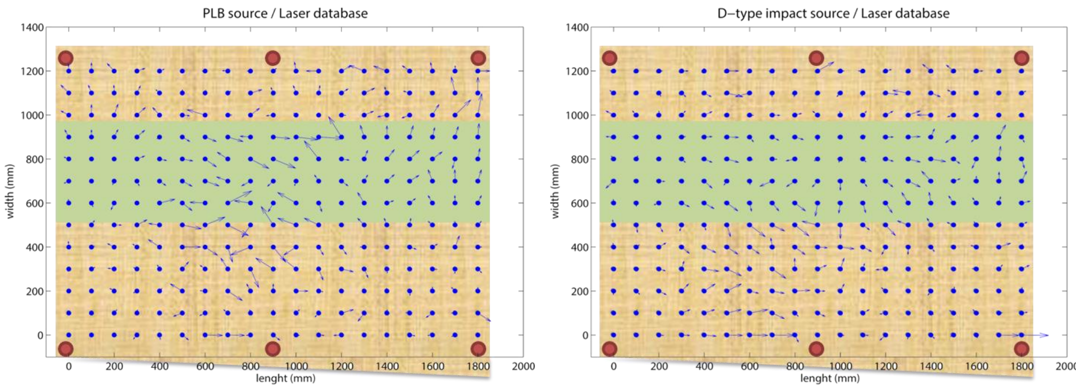



(a) sensor 1 (b) sensor 2 (c) sensor 3

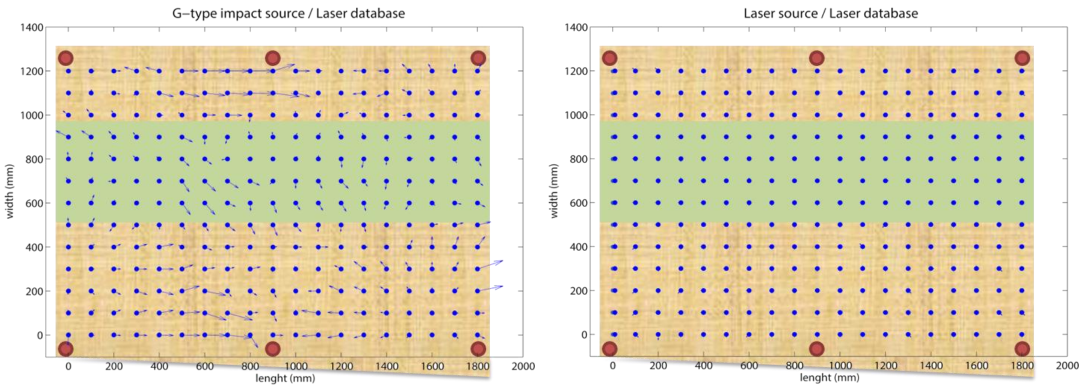
Figure 5: Contour map for each sensor (source: pulse laser, 4.61 Watt)

Fig. 6 shows the result of source location for the case of each different unkwon source using a database of pulse laser sources. Here, a blue dot indicates an original source point and the arrow indicates a direction and size of location error. As shown in figure, the location error increases in case of a big difference between input source and database sources. The smaller energy signal than the selected database gives irregular error direction. On the other hand, the larger energy signals than selected database shows specific error direction.

Fig. 7 shows the results of correlation between source location error and damage index error. In case of the Equo-tip-G type source we can see high index error, since most of signal deviated from the database of pulse laser source. Therefore PLB or Equo-tip-D type source shows low index error because the signal energy is similar to the ranges of pulse laser database. Consequently, it gives good result when there is high similarity between unknown signal and database to be used.




(a) PLB vs. Pulse laser (b) Equo-tip-D vs. Pulse laser




(c) Equo-tip-G vs. Pulse laser (d) Pulse laser vs. Pulse laser

Figure 6: Result of source location according to the impact sources

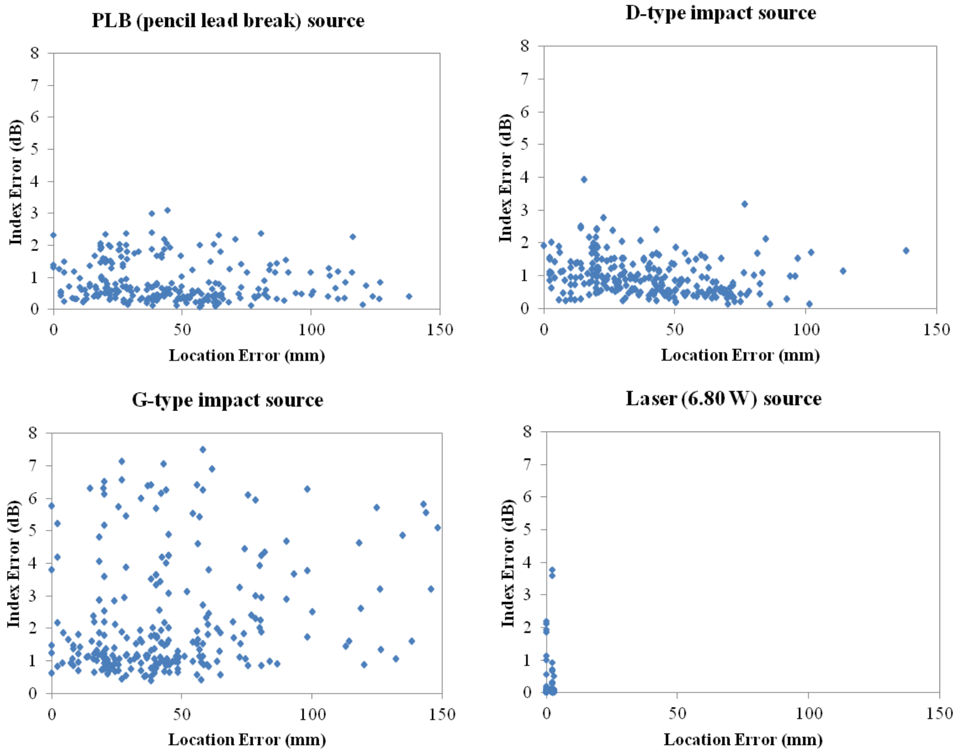



Figure 7: Source location error vs. damage index error

## CONCLUSIONS

Using a part of full scale wind turbine blade of 3 MW, the applicability of new source location method was confirmed by comparison of the result of source location and experimental damage location. From several experimental results, new suggested method of damage index identification showed very good performance for assessment of damages in the hybrid composites structures.

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