Acoustic emission and signal processing for fault detection and location in composite materials

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Abstract

The renewable energy industry is in a constant improvement in order to compete and cover any evolving opportunity presented. Nowadays one of those remarkable competitive advantages is focused on maintenance management and terms as operating and maintenance costs, availability, reliability, safety, lifetime, etc. The objectives of this paper are focused on the blades of a wind turbine. A structural health monitoring study is presented, that starts with the collection and analysis of data coming from different non-destructive tests. Signals from acoustic emissions are studied by a novel signal processing approach to detect cracks on the surface of the blades.

The case study proposes a new localization method using macro-fibre composite sensors and actuators. The monitoring system uses three sensors strategically located on the blade section. Among the main difficulties involved in this first approach, the modal separation of the wave is taken into account for its importance when drawing conclusions concerning the crack. This effect is the result of the blade breakdown, producing different signals at multiple frequencies. Another drawback is associated to the direction of the fibres in the composite material. This is known as slowness profile, a function depending on the propagation speed.

On the other hand, the main novelty of the approach presented is that it is able to predict the failure. In addition, it can be considered an accurate analysis as the solution will be always a single point obtained from a graphical method, i.e. the location of the crack can be detected with precision. The results are also checked quantitatively using nonlinear equations.

Keywords: Acoustic emission, wind turbine, structural health monitoring, macro-fibre composite.

1. Introduction

The renewable energy industry is in constant improvement to cover the current demands and that implies that companies need to take advantage of any evolving opportunities presented. One of these competitive advantages are focused on maintenance management. Wind turbines (WT) are one of the fastest growing sources of renewable energy production [1]. The complexity of these devices causes a reduction of the system reliability and raises the maintenance costs due to the occurrence of non-monitored failures [2][3]. There are several case studies that present maintenance activities on WTs depending on the model considered, the geographic and environmental changes that occur in different wind farms.

The introduction of non-destructive testing (NDT) for fault detection in structures as part of maintenance management programs have gained relevant attention in recent years [4]. This is due to significant advances in instrumentation technology and digital signal processing. Techniques for Structural Health Monitoring (SHM) permit to identify and diagnose the fault and its location on the basis of changes in static and dynamic structure features [5][6][7]. In addition, these techniques can be remotely controlled and they may work online saving important costs associated to manual inspections and warning times [8][9]. In summary, the productivity performance is maximised, and possible downtimes of the WT are minimised. This results in an increasing of the reliability, availability, maintainability and safety levels [10][11].

The purpose of this paper is to design a fault detection and diagnosis model to monitor the structural condition of a blade. The case study proposes a localization method using macro-fibre composites. Three sensors are strategically located along a blade section to detect incipient breakages on these structures. The case study involves a number of considerations to take into account, e.g. the appearance of the scattering phenomena, the orientation of the sensors and fibres when receiving the excitation, etc. However the method is able to detect the location of a crack with accuracy. The analysis gives as the result a single point obtained from a graphical method that is checked mathematically using nonlinear equations.

The article is organized as follows: Section 2 describes the blades experimental system. Section 3 explains the method to locate the crack from acoustical emissions. Signal processing and results are detailed in Section 4 and, finally, the main conclusions are drawn in Section 5.

2. Blades experimental system

The experiments are performed on two pieces of a WT blade due to the inability to handle a full blade in the laboratory. The first fragment (see Figure 1, left), where an experiment for the detection of mud is performed, is made of glass reinforced plastic. This type of material has a versatile manufacturing, good structural properties and resistance to fatigue among other advantages. It has also a low expansion coefficient and low electrical conductivity, making such materials particularly interesting for protection against lightning. Furthermore, composite materials are transparent to electromagnetic waves. The second fragment (Figure 1, right) consists of multiple layers. One of the ends is composed of a Honyecomb central layer embedded between two fibreglass layers made of polyester resin. The other end is thinner and assembled from two fibreglass layers. The remaining experiments are performed on it.

Figure 1. Blade fragments.

3. Location of the fibre breakage by acoustic emissions

Detecting the emergence of defects and/or faults is as important as detecting the exact location for the blade monitoring. Thus any corrective or preventive action can be implemented as soon as possible.

A location method by triangulation using three macro-fibre composites (MFC) [12] is performed to reach the objective of this paper. A MFC is a polymeric matrix made of piezoceramic fibres embedded between phases of adhesive film with electrodes that transfer voltage to ribbon-shaped rods and *vice versa* [13]. Its flexible nature allows the material to adapt to complex surfaces. They offer excellent qualities in performance and repeatability over traditional materials. The MFC does not introduce mass or stiffness when they are incorporated in structures.

These sensors act as signal receivers in the case study. When a fibre-break occurs, the elastic waves reach the MFC and the signals are recorded. The micro-breaks liberate energy out of the material [14]. This energy takes the form of an elastic wave that produces sound. The sensors translate the mechanical energy in small electrical signals, which usually are pre-amplified in order to obtain a clearer signal. The signals can be stored in a computer for later analysis. The frequency of the signal produced by the micro-breaks depends on several factors, e.g. the nature of the material, the type of discontinuity and the source of the emission. On this base it is possible to characterise the source of the emission by isolating certain frequencies with the help of appropriate filters.

Several experiments are conducted to achieve the target. The acoustic emission produced by the division of the glass fibres is simulated by breaking the tip of the lead of a mechanical pencil. Previously, the emission rate needs to be calculated on the blade. Multiple tests are done applying the same force, angle of inclination and length for the lead. This is intended to get similar signals for all the case studies. As stated before, the raw data (Figure 2) will be filtered for a better processing and removal of unwanted frequencies.

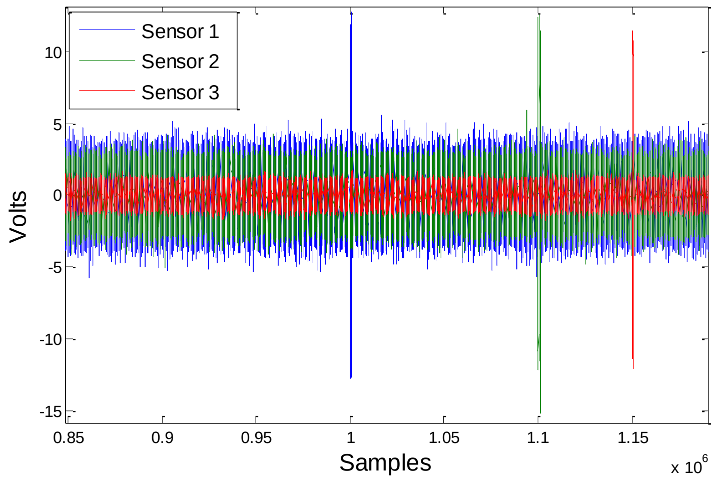

Figure 2. Crack delay signal simulations.

The wavelet transform is introduced for this purpose. Wavelet transform is a tool applied to time and frequency domain analysis with the use of several decomposition coefficients at different frequency bands [15]. It can work with high and low frequencies, identifying spectral features, unusual temporary files, and lack of stationary and removing random noise [16]. The wavelet transform improves the limitations of resolution; and the loss of information presented by other filtering methods [17][18]. Research into leak detection in plastic pipes from acoustic emission signals [19], cracks [20] or evaluation of the corrosion on non-accessible pipes can be found [21] based on wavelet transforms.

Wavelet transforms are commonly categorized as continuous wavelet transforms (CWT), discrete wavelet transforms (DWT) or wavelet packet transforms (PWT) among others. All these types emerge from what is known as mother wavelet, which is given by the equation (1).

$$\Psi_{s,\tau}(t) = \left(\frac{1}{\sqrt{s}}\right)\Psi\left(\frac{t-\tau}{s}\right) \tag{1}$$

where s is the scale factor, and τ is the translational factor. The wavelet transform $Wf(s,\tau)$ of a function f(t) is the decomposition of f(t) in a set of functions forming a base with the conjugate of the mother wavelet ($\psi^*s,\tau(t)$). It is defined in equation (2):

$$W_f(s,\tau) = \int f(t)\psi^*_{s,\tau}(t)dt \tag{2}$$

3.1. Triangulation and mathematical model

A triangulation is a process to determine the location of a point by measuring angles from known points [22]. Three sensors are required to determine the source of the emission from the acoustic signal generated by the rupture of the lead [23]. In addition, the location of the defect can be mathematically solved from a system of nonlinear equations. Its accuracy will depend on whether the variables are correctly initialized or not.

The equations to solve this problem need to be initialized from different coordinates and radii; and the solution gives the coordinates of the defect using an algorithm previously designed. The input values will be different locations close to the intersection of the three bisectors of the triangle generated from the three sensors.

4. Results

The time of flight as well as the distances is calculated for two sensors with respect to the third one, which is the first sensor to receive the acoustic signal of the breakage. The experiments are also repeated to take into account possible deviations of the results. Known the radii of the first two sensors, the algorithm gives the exact coordinates of the crack as well as a graphic outline. The dimensions of the blade must be included as an input in the algorithm. The mathematical results obtained with the program are recorded and saved.

This experiment involves a number of considerations to take into account. As many frequencies are excited to simulate the defect, different waves at different speeds appears as a result of the scattering phenomena. This fact makes difficult the identification of delays. Moreover, the orientation of the sensors when they receive the excitation, it determines the type of signal stored.

Either way, the algorithm works correctly and detects the location of the acoustic emission for the simulated fault from the signal received by the three MFC's with high precision. The delays between the arrival of the signal to the remaining sensors regarding to the defect show the instability and degradation/attenuation that is found at the beginning and the end of the blade. It is also noted that the signal moves forward changing its speed depending on the area where the sensor is located. This is because the blade is not homogeneous.

5. Conclusions

The growth of the renewable energy industry and the needs to reduce costs and increase competitiveness, safety, availability, reliability, forces firms to emphasise to invest and improve areas as the maintenance. The development of a localization method using macro-fibre composites to detect cracks in blades is proposed as part of a SHM system. This approach based on NDT tests automatically identify, locate and determine the severity of a defect in any structure.

Three sensors are strategically located along the tested section and using a graphical method based on triangulation and supported by nonlinear equations, the approach is able to detect the location of the acoustic emissions for the simulated cracks with great accuracy. Different experiments are performed to confirm the effectiveness of the proposed method.

These actions can be introduced within the maintenance management policies of any wind farm. This can be translated into a significant improvement since the information can be enhanced and implemented in dependable embedded computer systems.

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