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Modal acoustic emission for composite structures health monitoring: Issues to save computing time and algorithmic implementation

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ABSTRACT

This paper deals with assessing the integrity of composite structures via modal acoustic emission (MAE) technique. It is a continuity of the paper "On the modal acoustic emission of composite structures", published last year by the authors in the same journal. To improve the reliability level of this technique (as it is the case of the other nondestructive techniques), exploring various innovative processing techniques of the collected data is required. Unfortunately, this task undergoes a huge volume of data, where its management (processing, reuse, etc.) should be achieved as well as possible. Hence, performing an efficient processing of the large data sets that can be generated via MAE, during the composite structures health monitoring, is a challenging topic. This study concerns the development of an algorithmic tool for resolving the problem of memory saturation, which can be encountered when working with such large data sets. It is a first step towards Big Data based solutions, launched recently by the authors' team. A case of study is discussed, showing the robustness of the already implemented algorithmic tool.

1. Introduction

Composite structures are in permanent increase use in many fields such as vessels in transport and energy [1,2], large shell in aeronautics [3], tubes in oil and gas [4], bars in civil infrastructures [5], etc. Mechanical performances of this kind of structures depend on various parameters related to the loading pattern, structural design (winding angles, lay-ups sequence...) and also to the damage state. Damage mechanisms are manifold but the main types are generally matrix cracking, delamination between layers and fiber breakage. It is well known that damage develops early in service and accumulates during service life [6]. Depending on the load and/or mechanical impact characteristics, damage type and rate will be different and could have an influence on the ultimate failure [7]. For this reason, the study of the tolerance to damage and the relationship between mechanisms and the reduction of stiffness is a crucial task. For example, when laminates composite is subjected to flexural fatigue loading, transverse matrix cracks (TMC) is generally the first damage that occurs in the outer plies and grows through the thickness to the other group of plies [1,8]. The multi-cracking is another damage mechanism, which is well described in literature such as in Garret and Bailly [9]. When a matrix crack appears, a part of the load is transferred to neighboring plies and at a certain level of stress, a new crack appears. Some experimental and numerical works have been established the influence of cracks density on stiffness changes [10]. Usually, stiffness change due to TMC is not critical as such but it precedes other critical damage mechanisms [11], and its detection by means of non-destructive techniques could be used as an early warning to avoid catastrophic failures [12]. During the charge transfer from the cracked layers to the adjacent ones, delamination may be created when loading exceed the yield strength or delamination resistance. Fiber-bundle breakage is the most severe kind of damage that can be dangerous for the structure [13]. Fiber strength is very high and its breakage is the result of a high loading pattern along the fiber axis [14].

Identification of damage mechanisms using a non-destructive technique is essential in the life cycle of such a composite structure. This helps ensuring a more efficient preventive maintenance since it is to be achieved in an early stage of eventual defects. This offers a pragmatic benefit to the maintenance team, which is having enough time to react. The more realistic decision to be made is achieving more regularly this non-destructive testing. Basing on the aforementioned damage mechanisms analysis, increasing the frequency of site intervention (to do measurements) allows determining the velocity of damage evolution. This would be a primordial input to predict the structure residual life. We speak hence about predictive maintenance, which is a relatively new thematic that starts gaining ground the last years in many fields. Moreover,

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another main advantage is that knowing damage mechanisms (and so the root-cause of failures) should be helpful to improve the design of the next future generation and possibly better managing the load solicitations, to be more robust and so, more safe for assets and people. Modal acoustic emission (MAE) [15] is a potential candidate for reaching these aims. The main advantage of this technique is that it offers possibility to perform a global testing or monitoring of a given structure using sparse sensors, and so win time and cost (comparatively to the other local techniques such as ultrasonic phased array [16,17]).

Unfortunately, although it is a promising technique as it is shown in [15], its implementation is not a trivial item. The ultimate objective of this paper is so to detail the algorithmic aspects that permit achieving MAE. It should be noted that when operating with MAE as well as classic AE, data analyst are confronted to a huge amounts of data. The challenge is then how to overcome this problem by automatizing as match as possible the analysis of the collected data, and so having a quick access to the result. All this should be executed via a relatively classic microcomputer. The problem that the data analyst should face in the current case is, as it were, a problem of Big Data [18], but at a relatively small-scale.

This paper consists of six sections. The second one is devoted to better explain the concept of MAE technique as well as the motivation of achieving this work and writing this paper. Section three is dedicated to describe the experimental set-up and approach used in this work. Section four is reserved to detail the algorithmic implementation. Results are discussed in section five. Conclusions and outlooks of this study are the target of the last section.

2. Background and motivation

This section concerns the definition of the MAE and the motivation of running this study. The fact that MAE is a relatively recent technique rends the difference between it and the well-known AE [19] ambiguous. Actually, the difference is slight and is somewhat based on some subtleties. MAE can be considered as a derivative of AE, the mother technique. From the point of view of physics of waves' propagation, both techniques are based on guided waves. When generated by an event (such as a damage mechanism), waves will propagate in a structure with possible various modes of propagation [20]. These modes have different velocities of propagation. For this raison, one event generating one echo, at a given time, may give rise to a signal consisting of several echoes. For illustration, let us examine Fig. 1 (left), which presents a typical signal. As it can be seen, two echoes (i.e. wave packet) are present; this means that the event which generated this signal (said also waveform) provided two different modes. While AE uses this specificity simply as a number of counts (in the current example, this number is equal to two), MAE aims to exploit it (i.e. wave modes types) for determining source orientation and thus, identifying damage mechanisms. The relationship between source orientation and the generated mode type is largely studied in literature [6].

Theoretically speaking, there is infinity of guided wave modes, see textbooks of mechanical guided waves such as [20]. In practice however, only few modes can propagate and be received by the used sensor. This is due to many factors: the type of the damage mechanism, the attenuation of waves in the medium, the type of the sensor and its frequency bandwidth, etc. In MAE, the modes to be exploited are fewer and are namely the symmetric mode (called also extensional or compressional) and the asymmetric (named also flexural). Compressional and flexural modes are in reality two families or modes, where each one consists of many modes with different orders. In MAE, only the predominant modes are those used for analyses. The lowest symmetric order mode may be generated by matrix cracking and fiber fracture whereas the lowest asymmetric order mode is generated by delamination. By analysing the energy and frequency content of waveforms, it is possible to sort the predominant mode and thus identify the source. Many works can be found in literature [21] where the more recent (to the knowledge of the authors) is the one published one year ago by them [15], in which a novel method to assess damage mechanisms has been proposed.

The main technical problem that should be encountered when appealing the proposed method is its numerical implementation. Indeed, a composite structure is, by definition, a very high emissive medium. During a relatively short time of monitoring (whatever with MAE or AE), many millions of signals can be recorded. Many Giga octets can be recorded in just one experiment and one small structure. Fig. 1 (right) is given here for a purpose of illustration, where a very high density of points can be seen. Every point corresponds to the maximum amplitude of one signal. That is to say that each data array (i.e. signal) is transformed in only one datum. This

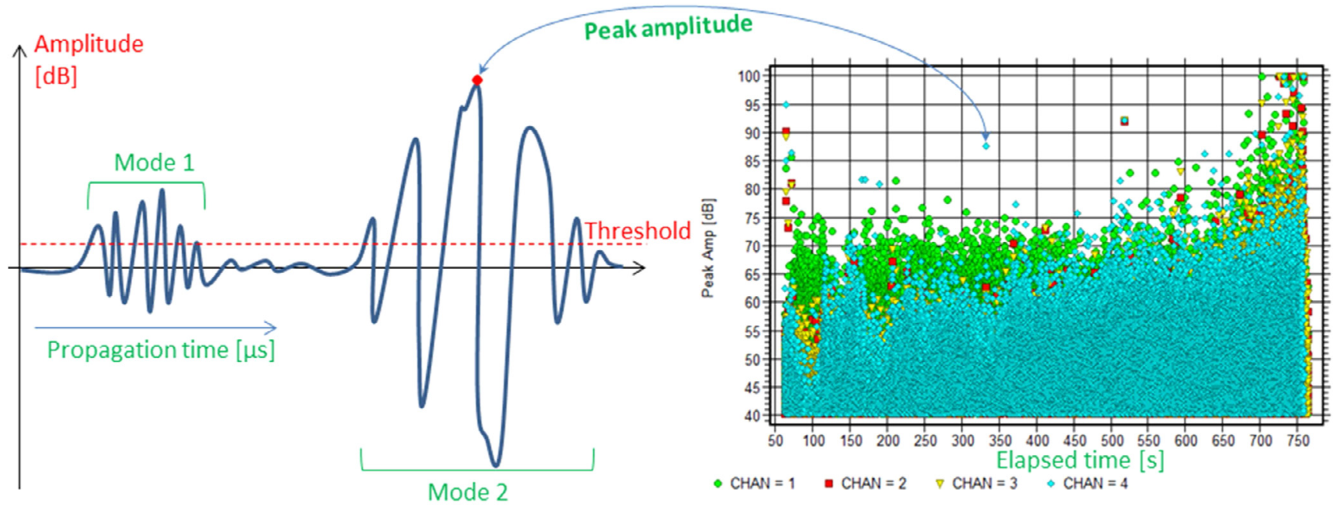

Fig. 1. Schematic representation of a typical acoustic emission waveform (left) and acoustic emission activity (right) (CHAN indicates channel; 4 channels were used to perform acquisitions).

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