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FATIGUE DELAMINATION MONITORING IN COMPOSITE STRUCTURES BY GUIDED WAVE METHOD

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Abstract. This paper presents an effective parameter for fatigue delamination detection and monitoring by guided wave method. The finite element analysis and the Time of Flight parameter defined as a time between guided wave interrogated by an actuator and first wave captured by a sensor was introduced to observe the behaviour of the defected structure. The relationship between ToF and delamination size for different localization of the defect is presented for different configuration of the composite beam.

1 INTRODUCTION

The dynamic development of the contemporary technology caused a significant change in the design methods of the engineering structures. The composite structures are widely used as an alternative solution for typical materials especially in aircraft and civil engineering structures. These materials are frequently subjected to static and dynamic cyclic loads. The safety and reliability of the structures mostly depend on effectiveness of the monitoring methods. The necessity of permanent monitoring the state of the structures and prognosis of the service life, as well as the economic aspects associated with optimal utilization of the machines and limitation of the maintenance time brought about the development of the Structural Health Monitoring (SHM) methods and systems. The number of non-destructive inspection technics grows and depend on engineering application [1],[2]. A literature review which summarize the methods of data acquisition, signal processing, feature extraction and data fusion techniques can be found in Refs. [3],[4],[5]. The guided wave propagation is one of the most efficient method for damage detection. The techniques of the damage identification are the subject of interest for researchers both in time and frequency domain for three decades. A classification of dynamic-based SHM techniques as a relationship between interrogation frequency and damage size was presented by Gopalakrishnan et al.[6]. A several techniques of inspection have been developed in time domain. A time-of-flight (TOF) method with techniques of data fusion has been presented by Xu, Yu and Giurgiutiu [7]. A direct comparison of the signals from defected and intact structures has been utilized by Kessler [8] and Giurgiutiu [9]. The guided wave method is also utilized to monitoring the fatigue crack and delamination in beams and plate-like structures [10],[11],[12]. It is worth to point out that the majority of research about fatigue damage detection and monitoring deals with isotropic structures. Unlike metallic alloys, fatigue damage in composite multi-layered structures can initiate relatively early in their service life. Delamination is one of the most common type of damage in laminated fibre-reinforced composites due to their relatively weak interlaminar strengths [13]. The process of delamination propagation frequently starts from initial interlaminar crack that can enlarge under dynamic or cyclic loading history. The growth of the defect leads to structural integrity loss and reduction of the overall buckling strength. Both experimental and numerical analysis of a delamination growth in composite structures are investigated by many researchers [14],[15]. From reliability and safety point of view, the most important is early detection of delamination in composite structure, monitoring of the defect behaviour and assessment of service life of the defected structure.

2 FORMULATION OF THE FINITE ELEMENT MODEL

In this study the composite multilayered beam made of six prepreg layers with a single interlaminar delamination is considered (Figure 1).

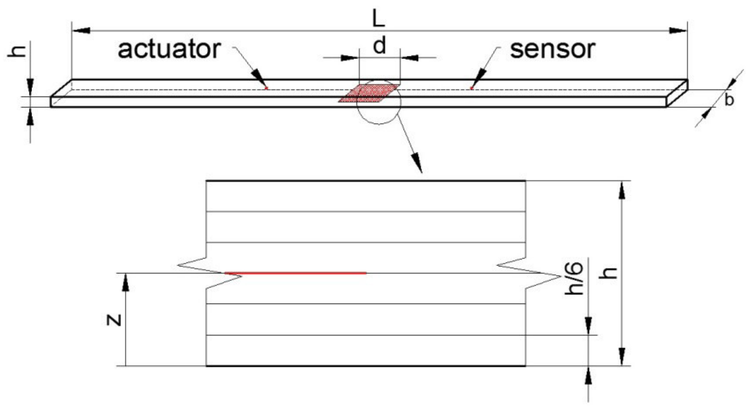

Figure 1: Composite multilayered beam with a single interlaminar delamination

The dimensions of the beam are equal L=600 [mm], h=2 [mm], b=10 [mm]. The material properties of the epoxy resin prepreg reinforced with unidirectional carbon fiber with a volume fraction of 60% (Hexcel AS4/8552) has been confirmed in experimental tests by Argüelles et al. [14]. The considered material are mainly used for motorsport application and in general the high performance car industry [16]. In this study the finite element ANSYS package was applied to evaluate the dynamic behaviour of the structure. An appropriate finite element model of guided wave propagation phenomena have to fulfil a several requirements which have been pointed out by Ye and Su [17] and applied to composite structures by Stawiarski et al. [18]. The higher order 3D finite elements have been utilized in numerical model of the beam. The interlaminar delamination have been introduced by duplicate node method (Figure 2). The localization of the defect is defined by *z* parameter (Figure 1).The actuator and sensor were placed 100 mm from the centre of the defect. The wave interrogated by an actuator (100kHz signal modulated by Hanning window) after propagation through the defected area was detected by a sensor and compared with the pattern signal from the intact structure.

Figure 2 The finite element model of the delamination.

The Time of Flight (ToF) parameter is defined as the time between the wave generated by an actuator and wave detected by a sensor (Figure 3). Interlaminar delamination in composite materials cause the distrubance of the guided wave and influence on the ToF parameter. The time lag between guided wave detected by a sensor for intact structure and wave disturbed by delamination can be used to detect and predict the evolution of damage.

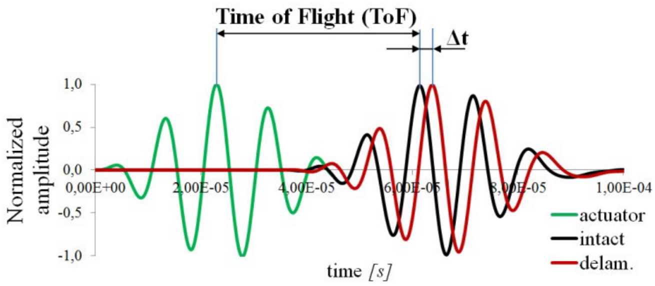

Figure 3 The definition of the Time of Flight (ToF) and the time lag (Δt) between guided wave from the intact and defected structures.

The analysis of time of flight is one of the most straightforward feature of propagating wave which can be utilized not only for damage detection but also for localization and identification of the defect.

3 RESULTS OF FEM ANALYSIS

To observe the ToF parameter for different size and localization of the delamination the different orientation of the prepreg layers in composite beam was considered. A comparison of the response signals from intact and delaminated structures for composite beam made of 6 epoxy resin prepreg layers reinforced with unidirectional carbon fiber is presented on Figure 4. In presented example delamination was localised in the mid-surface of the beam (between 3th and 4th layer) The time lag of the guided wave captured by a sensor for intact and defected structure increase with the size of the defect. Thus the ToF parameter can be utilized for detection and assessment of the size of the delamination.

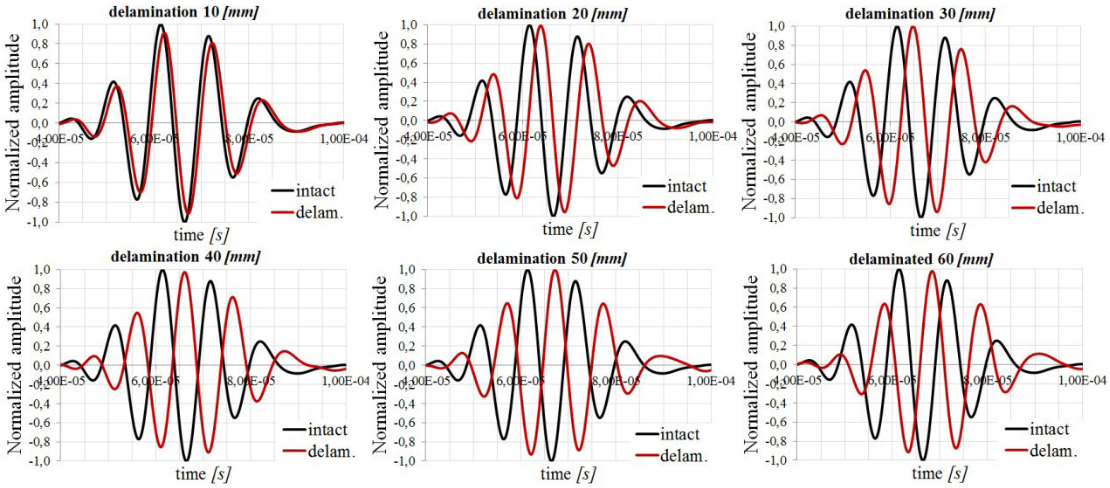

Figure 4 The guided wave captured by a sensor for intact beam and structure with different size delamination in the middle of the cross section.

The relationship between Time of Flight and delamination size for different localization of the defect is presented on Figure 5. The greatest increase of ToF can be observed for delamination localized in the mid-surface of the beam. For defect localized near the top and bottom surface of the structure the change of the time of flight is visible lower. The solid line on the presented figure is a linear approximation of the results for particular localization of the defect. The linear increase of ToF with the delamination length cause that the Time of Flight can be used for observation the evolution of the defect as well as for the prediction the delamination growth. It is worth to point out that ToF for delamination localized between layer 1 and 2 is very similar to delamination localized between layer 5 and 6. The same situation occur for interface 2 (between layer 2 and 3) and 4 (between layer 4 and 5).

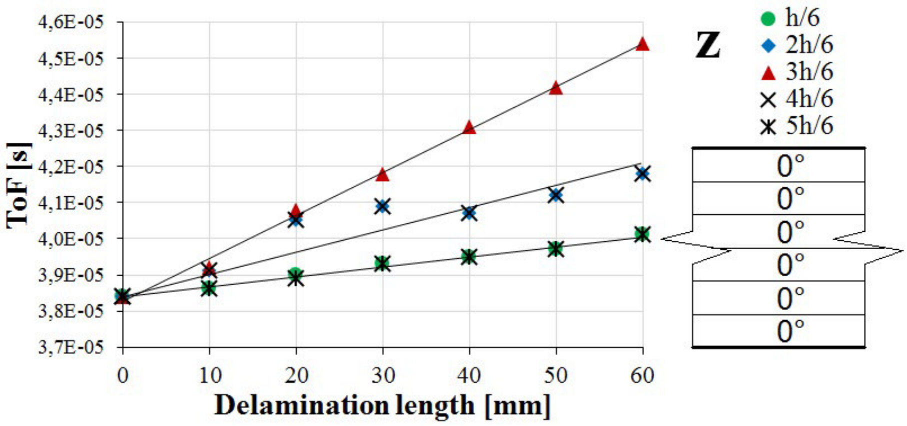

Figure 5 The relationship between ToF and delamination length for different localization of the defect for composite beam made of 6 epoxy layers reinforced along the length of the beam.

To observe the relationship of the Time of Flight parameter for symmetrical composite stackup the second configuration of the composite beam was considered ($[0,45,90]_S$). The results of guided wave propagation expressed as a Time of Flight parameter and configuration of the prepreg layers in a cross section are presented on Figure 6.

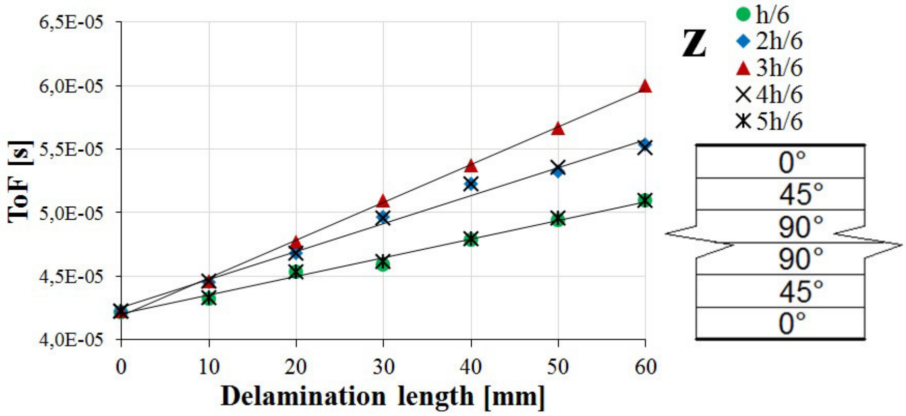

Figure 6 The relationship between ToF and delamination length for different localization of the defect for symmetric composite beam [0,45,90]$_s$

The linear increase of ToF for particular position of the delamination can be observed. The growth of the considered parameter is higher than for composite beam reinforced along the length. The similar behavior of ToF parameter for opposite delamination interface is observed. The greatest growth is observed also for defect localized in the mid-surface of the structure.
The unsymmetrical composite stackup ([0,-45,0,90,45,0]) was considered to compare the Time of Flight with the symmetrical composite beam. Results for this case are presented on Figure 7.

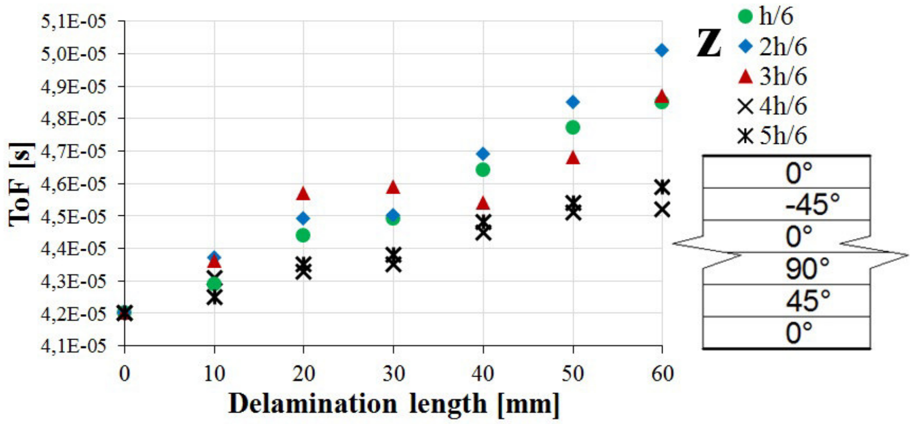

Figure 7 The relationship between ToF and delamination length for different localization of the defect for unsymmetrical composite beam [0,-45,0,90,45,0].

The growth of the time of flight with the delamination size is observed. The unsymmetrical laminate stackup cause the different behavior of the opposite delamination interface. In spite of the visible increase of the time of flight, the interpretation of the results according to the delamination position is not so obvious. It may difficult the observation and prediction of the evolution of the delamination growth. However presented results indicated that Time of Flight may be used for damage detection and assessment of the size without accurate identification of the position of delamination interface.

4 CONCLUSIONS

The Time of Flight of the guided wave is the straightforward parameter which can be utilized to damage detection and observation of the evolution of the delamination growth. The numerical results for symmetrical laminate stackup indicates that ToF parameter growth depends on the interface delamination position. The greatest increase is observable for delamination localized in the mid-surface of the structure. The unsymmetrical laminate stackup cause the difficulties in the interpretation of the results. However the increase of the time lag between guided wave from intact and defected structure may be used both for symmetrical and unsymmetrical laminates.

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