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Performance of vibration based damage detection algorithms for detection of disbond in stiffened metallic plates

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Abstract

Though vibration based health monitoring has been the focus of attention for quite some time, there exist a strong requirement for an extensive and comprehensive study on the relative performance of different damage detection algorithms under different damage scenarios. To fulfill this objective, a stiffened aluminium plate has been selected to make a comparative study on the performance of several vibration based damage detection techniques, namely, Modal Curvature, Gapped Smoothing Method/Modal Curvature, Generalized Fractal Dimension and Uniform Load Surface Curvature based on four different criteria: variation of damage intensity (i.e., disbond length), position of stiffener and disbond, the effect of noise and capability to detect multiple damage. In addition to this, a new approach, based on the curvature of wavelet coefficients, has been presented. It is found that this novel approach is extremely effective in determining the presence and location of damage under different situations. The entire numerical modelling is done in ANSYS 14.0 and the damage detection algorithms written in MATLAB codes have been used to generate the required damage indices using the modal data retrieved from ANSYS. The study ultimately enlightens inherent characteristics of the various damage detection algorithms under different damage conditions.

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Keywords: Delamination; Fractal Dimension; Modal curvature; Wavelet Transform; Uniform Load Surface

1. Introduction

Debonding is a very common phenomenon in composite laminated plates or between two metallic surfaces joined together by adhesives/weld. The problem with debonding is it would reduce the strength of a structure

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considerably without any visible outside symptoms. Herein lies the importance of constructing effective damage detection algorithms that would ensure early detection of damage, thereby, enforcing increased safety, durability and improved economic operation of the structures. An excellent review of the development of traditional type damage detection techniques between 1968 to 1996 has been given by Doebling et al [1]. In 2006 Hu et al. [2] developed a method based on modal analysis and strain energy method to find out surface cracks in composite laminated plates. Wu and Law [3] made the first significant contribution in the field of ULS-based damage detection in plate like structure. They extended the concept of Zhang and Aktan [4] to two dimensional case. Qiao et al. [5] studied the efficiency of experimentally measured data of two sensor systems (PVDF and SLV). Li and Huang [6] proposed another FD based algorithm for beams with uniform cross section using Katz's basic definition of FD. Rajasekaran and Varghese [7] proposed a wavelet based technique to identify the structural damage. Ratcliffe [8] developed a non-baseline based curve fitting algorithm for damage detection called the gapped smoothing method using modal curvature. Qiao et al. [9] made a comparative study of GSM, GFD and SEM for composite laminated plates using PVDF and SLV sensor systems. Recently, Luo and Hanagud [10], Hong and Chen [11], and Chen and Hong [12] have, respectively, carried out the dynamic response analysis of a delaminated beam and plate by employing a piecewise linear spring model inserted in the delaminated region. Qiao et al [9] made an alternative arrangement to model the delaminated region. The delamination conditions are simulated in the FE model by using the bilinear LINK10 elements.

While several studies have focused on delamination detection in composite beams and plates, there is a lack of detailed and comprehensive performance evaluation of different damage detection algorithms and their comparative study. The present study is made to find an effective model for delaminated stiffened plate and to judge the applicability of different existing vibration based damage detection algorithms under different damage scenarios. Effort has been made to evaluate the accuracy of the detection algorithms using noise-adulterated data.

2. Damage detection algorithms

2.1. Modal curvature (MC)

In modal curvature type damage detection, mode shapes are measured and the curvature calculated at each node. There exists a direct relationship between curvature *(κ)* and bending strain *(ε)*:

$$\varepsilon = y / R = ky \tag{1}$$

Where, *ε, y, R* and *κ* are the bending strain, transverse deflection, radius of curvature and curvature respectively. The curvature of mode shapes (κ_i) are derived using a central difference approximation applied on the mode shape data (φ_i) [13].

$$k_i = \frac{\varphi_{i+1} - 2\varphi_i + \varphi_{i-1}}{h^2} \tag{2}$$

The concept of modal curvature has been extended to 2-D for the case of aluminum plate. The discrete displacement mode shape values are collected from the ANSY S result file and arranged in a m×n matrix (grid) form. The curvature of mode shape is calculated using central difference technique along each of the grid lines. The difference between damaged and undamaged curvature is the measure of damage index *(DI(MC))* for modal curvature.