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ScienceDirect

Procedia Engineering 142 (2016) 182 – 189

Procedia Engineering

www.elsevier.com/locate/procedia

Sustainable Development of Civil, Urban and Transportation Engineering Conference

Damage Detection in Laminated Composite Plates Using Modal Strain Energy and Improved Differential Evolution Algorithm

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Abstract

In this paper, a model strain energy based method and an improved differential evolution algorithm are used to locate and quantify damage on the laminated composite plate. Firstly, the modal strain energy based method is employed to identify a set of potential damaged elements. Then the improved differential evolution algorithm is utilized to minimize a mode shape error with the damage variables to indicate the extent of elements defined in the previous task. The numerical examples carry out a three-layer square laminated composite plate with two damaged elements. In addition, the effect of noise on the accuracy of damage localization is also investigated.

Peer-review under responsibility of the organizing committee of CUTE 2016

Keywords: damage identification; laminated composite plate; improved differential evolution algorithm; optimization;

1. Introduction

Composite materials hold a large proportion in vehicle construction, particularly in aircraft, aerospace and automotive engineering due to their outstanding properties, such as high stiffness and strength, etc. Damage in

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Peer-review under responsibility of the organizing committee of CUTE 2016
doi:10.1016/j.proeng.2016.02.030

composite structures may significantly reduce their stiffness and then lead to tragic consequences. As a result, the development of reliable and efficient damage identification methods for composite structures is very important.

In the structural health monitoring (SHM) literature, vibration-based damage detection methods are widely used for composite structures. Some up to date reviews of these methods can be found in Refs. [1–4] and their application for composite structures is reported in [5,6]. In the categories of vibration-based damage detection methods, frequency change-based method, curvature mode shape-based method, modal strain energies method, flexibility based approach and mode shape based method have been applied successfully for composite structures like beams and plates [7–13]. Besides, some other damage identification methods, such as wavelet analysis method, optimization-based method, guided Lamb wave method [14] also employed to identify the damage location on composite structures. Although there are amount of damage assessment methods basing on vibration characteristics for composite structures, most of them have been limited to damage location only.

There have been some damage identification approaches based on the optimization algorithms were used to identify the location and extent of damage [4,15]. Several meta-heuristic optimization algorithms such as genetic algorithm (GA), particle swarm optimization (PSO), artificial bee colony (ABC) have applied successfully for structural damage localization [15–17]. However, the implementation of these optimization algorithms for locating damage in structure still have some tackles that need to be addressed. For example, (1) the accuracy of the optimization algorithms, (2) the expensive computational cost of the optimization algorithms, (3) the invalid of the optimization algorithms for dealing with large design variables. Besides, the application of these damage identification approaches for composite structures is still somewhat limited.

Based on the above considerations, the damage localization method for laminated composite plates using a modal strain energy based method and an improved differential evolution algorithm is presented in this study. Firstly, the model strain energies-based method [18] is used to identify possible damage elements as well as reduce the design variables for the implementation of the optimization algorithm. Then, the improvement of the differential evolution algorithm is utilized to identify extent of damage and also to reduce the false alarms of elements found in the previous task. The numerical examples consider a laminated composite plate with multiple damages. Moreover, the effect of noise on the accuracy of the proposed procedure is also investigated. The numerical results show that regardless of the effect of noise, the improved differential evolution can locate and quantify damage with less computational effort than the standard differential evolution algorithm.

2. Damage locating using modal strain based method

The modal parameters of structure, such as frequencies, mode shapes, and damping ratios are related to the damage in structure. Therefore, the change of these modal parameters between damaged and healthy structures was used to locate damage. In addition, the change of flexibility matrix, mode shape curvature and modal strain energy established by these modal parameters is also considered as efficient indicator of damage. In the previous studies [1], [19], authors proved that the change of the modal strain energy is better than the change of the other ones at locating the damage. In this paper, a model strain energy based method [18] using model strain energy change ratio (MSRCR) as damage indicator is extended to identify the location of damage on laminated composite plates.

3. Damage severity assessment

One type of damage identification methods is to transform the damage localization into an optimization problem in which the objective function is defined as the difference between the modal parameter of the damaged and healthy structures. The variables of the problem are defined as the damage severity of elements. Many kinds of various objective functions have been proposed by previous studies. Some typical objective functions can be mentioned as the frequency error [20], the MDLAC coefficient (mode shape) [21], the flexibility matrix [22].

3.1. Objective function based on the mode shape error

In this paper, an objective function *f* based on the change of mode shape is defined as follows