PHYSICAL AND MATHEMATICAL SCIENCES

UDC 699.88

WAVELET CRACK DAMAGE DETECTION IN COMPOSITE PLATES

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Abstract: The method for detecting mechanical damage in composite structures proposed in this paper is based on the study of the energy of structural dynamic responses. Continuous damage detection was carried out using wavelet analysis. The results obtained in this study show that the minimum damage sizes are in the submillimeter range. This method is suitable for detecting damage in hard-to-reach places of structures without using an additional excitation device.

Key words: wavelet analysis, composites, damage detection, health monitoring, matrix crack damage.

Mechanical damage associated with discrete matrix crack fields in laminated composite plates has been the subject of intensive research for quite a long time. For a large number of laminated composite structures used in various industries, crack damage [1, p. 746] will occur, for example, during their operation due to aging, chemical degradation [2, p. 424], mechanical vibration and impact, etc. The above facts illustrate the reasons why real-time detection of composite damage is a hot topic and should be given great attention [3, p. 1315]. During operation, matrix damage by cracking can lead to deterioration in performance and even failure of composite materials.

It is obvious that early detection of incipient damage and continuous monitoring of the growth and location of damage in the structure require the implementation of automatic damage control of operating structures. One of the most important research tasks is the localization of individual damages based on the analysis of the dynamics of multiple cracks throughout the volume of the laminated composite [4, p. 1355]. Different forms of structural damage cause, respectively, individual changes in the structural mechanical properties. A large number of experimental and analytical studies on vibration characteristics in the bulk of a composite specimen are one of the most effective methods for identifying structural damage. Many strategies such as the modal frequency approach, the transmission function approach, the resonance approach, and the mechanical impedance approach that compares the piezoelectric conductivity signature with the healthy baseline signature and the wavelet-based approach have been used to detect structural damage.

In this study, the dynamic responses of laminated composite to fixed spectrogram of piezoelectric patches are analyzed. The dynamic model of the plate is established using the finite element method and micromechanical theory of composite damage. According to the energy distribution of the decomposed structural dynamic responses using wavelet packet analysis in different frequency ranges, an index vector is extracted for structural damage detection. It is shown that a very small crack damage region in the laminated composite plate can be well identified when the structure is driven using an excitation signal with sufficient frequency components.

The computational model was based on governing equations in which displacements at an arbitrary point of a thin laminated composite plate were represented as explicit functions of mid-plane displacements and additional rotations due to shear strain. For a composite plate, the strain and mechanical stress ratios in a fixed layer with anisotropic behavior were determined by the matrix of stress and strain vectors, respectively. In turn, the elements of the stiffness matrix depended on the values of the elastic moduli, shear moduli, Poisson's ratios, and the fiber orientation angle of the laminated composite plate layer. Wavelet analysis of time-varying vibration signal in the volume of laminated composite is a kind of localization analysis method in time and frequency domains, and the time and frequency windows can be changed. This signal processing method has higher frequency and time resolution. The continuous wavelet transforms of the function used to detect deformation regions were determined by the translation parameter, the scale parameter and the mother wavelet. The wavelet packet analysis method used in this paper made it possible to adaptively select the appropriate frequency band according to the characteristics of the analyzed signal and, in addition, significantly improve the resolution in the frequency and time domains.

The analysis of wavelet transform results showed that the time domain waveforms of wavelet decomposition signals from intact and damaged composite plates cannot directly indicate the damage state of the plate. However, their energy spectrum can clearly reflect the state of structural damage. The energy spectra of wavelet signals of vibration response from an intact plate and a damaged plate with a limited number of cracks clearly indicate the presence of damage. Taking into account the changes in energy spectrum obtained by wavelet analysis will allow us to detect 0.01–0.1% of the extent of structural damage. As a conclusion of this study, it can be stated that the initial damage of crack in composite plates can be effectively detected using the energy change of structural vibration response decomposed by wavelet analysis. The adopted vibro-electrical structure analysis technique is also useful for active and rapid detection of structural damage. The local physical behavior of the structure can be determined using global structural dynamic characteristics.

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