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Investigation on Selection of Optimal Mother Wavelet in Mode Shape based Damage Detection Exercise

Naresh G. Jaiswal[a,]*, Deepak W. Pande[b]

[a]*PVG's College of Engineering & Technology, Pune-411046, India*
[b]*College of Engineering, Pune-411005, India*

Abstract

The materials of the structures in use are always subjected to degradation in its characteristics over the period of time. The reduction in stiffness is always associated with such degradation. The analysis of vibration response of such materials with appropriate signal processing techniques has always led to the solution of damage identification exercises. The aim of the paper is to evaluate the performance of mode shape based technique along with wavelet transform through simulated model of structure- a cantilever, in damage identification exercise. A small transverse cut of wire thickness is introduced in cantilever beam. Depth of wire cut is varied to intensify the damage at various locations. Number of flexural modes are extracted from finite element modal analysis. Spatial continuous wavelet analysis is carried on number of modes. Effectiveness of different biorthogonal and reverse biorthogonal mother wavelets is studied to investigate the efficacy of the method. The proper selection of analysing mother wavelet influences the desired information extraction and its amplification process. The most suitable mother wavelet is recommended considering the nature of variation of wavelet coefficients.

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Keywords: Damage detection; Mode Shape; Signal Processing; Wavelets.

1. Introduction

Structural degradation of the critical structures because of damages, such as cracks, delaminations etc. or because of ageing are inevitable in aerospace, aeronautical, mechanical and civil engineering during their service life. To

* Corresponding author. Tel.: +91-020-24228258; fax: 91-020-24226858.
E-mail address: ngj_mech@pvgcoet.ac.in

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ensure the structure integrity and prevent the structural damages from the deterioration, the suitable damage detection techniques are required.

Vibration based damage detection are categorized as non-destructive type and they characterize the global properties of the structure. Number of such methods has been studied widely since last few decades. In most cases, structural damage identification is based on extraction of features from pre-damage state and post-damage state. The core of any such method is the feature extraction from the raw data and further amplification so as to reveal the level of damage at tiny scale. The obtained parameters may be in the form of natural frequencies, mode shapes, mode shape curvatures, modal strain energy, operating deflection shapes, frequency response function etc. Several methods have been reported in the literature to identify and locate damages. Many of the techniques on vibration based non-destructive methods can be found, in [1], where the authors introduced different methods based on evaluation of natural frequencies, frequency response functions (FRFs), modal assurance criterion, frequency domain assurance criterion etc. A similar study on model upgrading techniques using certain quality parameters based on natural frequencies, modal shapes, and FRFs was depicted in [2]. Patil and Maiti [3] have used a method for prediction of location and magnitude of multiple cracks based on extraction of natural frequencies data for cantilever beams. The verified damage index indicates the degree of strain energy stored in the rotational spring. The numerical and experimental results are presented. Mode shape based method finds wide space in damage identification solutions. The basic premise underlying this damage assessment is that damage existed in the structure under consideration causes local variation in its stiffness. The mode shapes capture such changes much better than natural frequencies. Hamey et al.[4] assessed many damage detection methods in composite beams with various damage scenario using curvature mode shapes. Other studies on analysis of curvature of mode shapes can be additionally found in available literature [5],[6]. Yan et al. [7] put forward an idea to recognize the modal strain energy as a function of damage magnitude and location. One more intriguing strategy was adopted by Sazonov et al. [8], where the authors measured strain at many places corresponding to each resonant frequency. This feature was reported to be of high sensitivity and accuracy. In an effort to improve the sensitivity of all such features various techniques have been explored till date. The technique suggested by Ratcliffe [9] had used the modified Laplacian operator on mode shapes data, which later manifested in quantitative localization of structural damage. Since the last decade, the wavelet transform, a promising tool for signal processing has been discussed in the literature may be due to its inherent ability to portray the data in time and frequency domain unlike Fourier transform. This approach involves application of wavelet transform to various features of vibration. Lu and Hsu [10] presented one of the methods based on wavelet transform for structural damage identification. The author established the method to detect and localize damage. In [11], the authors presented numerical study on spatial continuous wavelet transform (CWT) with Gabor wavelets for beams. Several experimental studies were performed on cantilever composite beams with single and multiple damage sites using discrete wavelet transform with B-spline wavelets [12].

Although the existing strategies reported in the literature are feasible to some extent to solve the damage identification problems, the emergence of new methods, tests, numerical simulation and evaluation of modern computational tools are always required. The aim of the present paper is to ascertain the feasibility of mode shape based technique along with wavelet transform suggesting suitable type of wavelet.

Nomenclature

$f(t)$	signal to be analyzed
$\psi(t)$	mother wavelet
a, b	dilation and translation parameter
$\hat{\psi}(t)$	fourier transform of $\psi(t)$

2. Numerical Modal Analysis

To ascertain the effectiveness of various biorthogonal and reverse biorthogonal wavelets in damage identification, finite element modal analysis and subsequent continuous wavelet analysis is done for cantilever model. The damage is simulated as thin transverse cut. To intensify the severity of damage the cuts are made deeper.