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ScienceDirect

Procedia Engineering 172 (2017) 426 – 432

Procedia Engineering

www.elsevier.com/locate/procedia

Modern Building Materials, Structures and Techniques, MBMST 2016

Multiple damage identification in beam structure based on wavelet transform

Rims Janeliukstis[a]*, Sandris Rucevskis[a], Miroslav Wesolowski[b] and Andris Chate[a]

[a]Institute of Materials and Structures, Riga Technical University, Riga, Latvia
[b]Department of Structural Mechanics, Faculty of Civil Engineering, Environment and Geodetic Sciences, Koszalin University of Technology, Koszalin, Poland

Abstract

In this paper a damage identification algorithm for beam structures with multiple damage sites based on wavelet transform method of vibration mode shapes is reported. A complex morlet function of order 1-1 is chosen as a wavelet function. Wavelet transform coefficients serve as a damage indices which are standardized according to statistical hypothesis approach, yielding a standardized damage index distribution over beam coordinate. The peaks with the largest amplitude correspond to the zone of damage. Finite element simulations of proposed methodology involving various artificial noise levels and reduction of mode shape input data points are carried out. Results show that the algorithm is capable of capturing the areas of damage.

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

Keywords: wavelet transform, beam, vibration, mode shape, damage identification.

1. Introduction

The need for cheap and simple methods for structural inspection has grown tremendously over past decades. This is due to the fact that complex modern engineering structures, for example, stadiums, dams, skyscrapers, tunnels, etc. have to maintain their integrity and functionality. Failure of these structures leads to tragic consequences as well as heavy material losses. Structural health monitoring (SHM) is an interdisciplinary domain which's prerogative is to evaluate the integrity of structures using non-destructive techniques. SHM can be classified into two categories – the

* Corresponding author. Tel.: +0-000-000-0000 .
E-mail address: Rims.Janeliukstis_1@rtu.lv

Peer-review under responsibility of the organizing committee of MBMST 2016
doi:10.1016/j.proeng.2017.02.023

ones that detect damage and the ones that not only predict the location and severity of damage but also service life of the structure [1].

While a wide range of vibration-based damage identification mechanisms exist, it is also preferable to employ such damage identification methods that do not require a baseline data of vibration response for a healthy structure, such as natural frequencies, mode shapes and damping. Unfortunately, only few of damage identification methods meet this criterion. One of such methods is Wavelet Transform (WT).

WT is a digital signal processing technique, capable of managing analysis of continuous as well as transient signals [2]. It has gained a wide popularity among many engineering communities and today is used in signal discontinuity detection, image compression and denoising, also in medicine and finance [3]. Several variations of WT exist, namely, discrete WT (DWT) and continuous WT (CWT). While DWT is less redundant in terms of decomposition of original signal into discrete levels, important features of a signal can easily be missed. Thus CWT is a preferable method in SHM due to a more detailed decomposition of a signal [4]. One-dimensional CWT is extensively employed in SHM, for example, single [5-10] and multiple [11,12] fault detection in beams and rotating machinery [13,14].

In this paper, two mill-cut damage sites are located in an aluminium beam using Continuous Wavelet Transform technique. The most promising wavelet function turns out to be complex morlet of order 1-1. Numerically simulated vibrational mode shape signals are corrupted with various levels of noise and reduced by several integer values to simulate the performance of damage detection algorithm in real life situations with different sensor densities. Results suggest that the proposed damage identification algorithm is capable of locating damage even at coarsest sensor grids and noise levels of up to 4 % assuming that appropriate wavelet scale is used.

2. Materials and methods

2.1. Wavelet transform

Mode shapes themselves do not reveal the location of damage, therefore special techniques are required. One of such techniques is Wavelet Transform. Wavelets are special functions $\psi(x)$ with small oscillations such, that their mean is zero. Wavelet transform is a mathematical method to transform the original signal into a different domain where additional data analysis becomes possible. Wavelet transform can be employed to analyse signals f not only in time domain but in space domain as well

$$W_{s,a} = \int_{-\infty}^{\infty} f(x) \cdot \frac{1}{\sqrt{|s|}} \cdot \psi^* \left(\frac{x-a}{s} \right) dx = \int_{-\infty}^{\infty} f(x) \cdot \psi_{s,a}{}^*(x) dx \tag{1}$$

where asterisk denotes complex conjugation and $\psi_{s,a}(x)$ is a set of wavelet family functions, derived from a *mother wavelet function* $\psi(x)$ by *translating* (parameter a) and *dilating* (parameter s) the $\psi(x)$. Parameter s is a real and positive number. If $0 < s < 1$, the function is expanded, if $s > 1$, it is compressed.

2.2. Damage detection algorithm

Equation (1) was used to calculate CWT coefficients, that are extremely sensitive to any discontinuities and singularities, present in the signal $f(x)$, therefore location of damage due to a sudden loss of stiffness can be detected in those mode shapes that yield large amplitude wavelet coefficients. Damage index for each of mode shapes is depicted as follows

$$DI_{i\ CWT}^{n} = W_{i\ s,a}^{n} = \int_{L} w_i^n \cdot \psi_{s,a}{}^*(x) dx \tag{2}$$

where L is the length of the beam, w^n is transverse displacement of the structure, n is a mode number, i is number of