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International Journal of Solids and Structures 42 (2005) 6610–6627

INTERNATIONAL JOURNAL OF SOLIDS and STRUCTURES

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Wavelet packet based damage identification of beam structures

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Received 1 August 2004; received in revised form 6 April 2005
Available online 8 June 2005

Abstract

Most of vibration-based damage detection methods require the modal properties that are obtained from measured signals through the system identification techniques. However, the modal properties such as natural frequencies and mode shapes are not such a good sensitive indication of structural damage. The wavelet packet transform (WPT) is a mathematical tool that has a special advantage over the traditional Fourier transform in analyzing non-stationary signals. It adopts redundant basis functions and hence can provide an arbitrary time-frequency resolution. In this study, a damage detection index called wavelet packet energy rate index (WPERI), is proposed for the damage detection of beam structures. The measured dynamic signals are decomposed into the wavelet packet components and the wavelet energy rate index is computed to indicate the structural damage. The proposed damage identification method is firstly illustrated with a simulated simply supported beam and the identified damage is satisfactory with assumed damage. Afterward, the method is applied to the tested steel beams with three damage scenarios in the laboratory. Despite the noise is present for real measurement data, the identified damage pattern is comparable with the tests. Both simulated and experimental studies demonstrated that the WPT-based energy rate index is a good candidate index that is sensitive to structural local damage.

Keywords: Damage detection; Wavelet packet transform; Energy rate index; Beam; Dynamic measurement; Signal process

1. Introduction

During the service of beam structures such as large-scale frames, long-span bridges and high-rise buildings, local damage of their key positions may continually accumulate, and finally results in sudden failure of

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doi:10.1016/j.ijsolstr.2005.04.031

structures. One damage identification classification system commonly defines four levels of damage assessment (Doebling et al., 1998): (1) the presence of damage; (2) the location of the damage; (3) quantification of the severity of the damage; and (4) prediction of the remaining serviceability of the structure. Basically, damage identification techniques can be classified into either local or global methods. Most currently used techniques, such as visual, acoustic, magnetic field, eddy current, etc., are effective yet local in nature. They require that the vicinity of the damage is known a priori and the portion of the structure being inspected is readily assessable. The global damage identification methods, on the other hand, quantity the healthiness of a structure by examining changes in its global structural characteristics. It is believed that these two methods should be used in a complementary way to effectively and correctly assess the condition of the health of a complicated structure.

One core issue of the global vibration-based damage assessment methods is to seek some damage indices that are sensitive to structural damage (Ren and De Roeck, 2002a,b). The damage indices that have been demonstrated with various degrees of success include natural frequencies, mode shapes, mode shape curvatures, modal flexibility, modal strain energy, etc. Doebling et al. (1998) and Farrar et al. (1999) summarized the comprehensive historic development of damage assessment methodologies based on these indices as well as pointed out their applicability and limitations. Most of vibration-based damage assessment methods require the modal properties that are obtained from the measured signals through the system identification techniques such as the Fourier transform (FT). The structural damage is typically a local phenomenon, which tends to be captured by higher frequency signals. The Fourier analysis transforms the signal from a time-based or space-based domain to a frequency-based one. Unfortunately, the time or space information may be lost during performing such a transform and it is sometimes impossible to determine when or where a particular event took place. To correct this deficiency, the short-time Fourier transform (STFT) was proposed by Gabor (1946). This windowing technique analyzes only a small section of the signal at a time. The STFT maps a signal into a 2-D function of time or space and frequency. The transformation has the disadvantage that the information about time or space and frequency can be obtained with a limited precision that is determined by the size of the window. A higher resolution in time or space and frequency domain cannot be achieved simultaneously since once the window size is chosen, it is the same for all frequencies.

The wavelet transform (WT) is precisely a new way to analyze the signals, which overcomes the problems that other signal processing techniques exhibit. Wavelet functions are composed of a family of basis functions that are capable of describing a signal in a localized time (or space) and frequency (or scale) domain (Daubechies, 1992). The main advantage gained by using wavelets is the ability to perform local analysis of a signal, i.e., zooming on any interval of time or space. Wavelet analysis is thus capable of revealing some hidden aspects of the data that other signal analysis techniques fail to detect. This property is particularly important for damage detection applications. Many investigators (Wang and McFadden, 1996; Kitada, 1998; Gurley and Kareem, 1999; Wang and Deng, 1999; Hou et al., 2000; Ovanesova and Suarez, 2003) presented applications of wavelet transform to detect cracks in frame structures. One possible drawback of the WT is that the frequency resolution is quite poor in the higher frequency region. Hence, it still faces the difficulties when discriminating the signals containing close high frequency components.

The wavelet packet transform (WPT) is an extension of the WT, which provides a complete level-by-level decomposition of signal (Mallat, 1989). The wavelet packets are alternative bases formed by the linear combinations of the usual wavelet functions (Coifman and Wickerhauser, 1992). Therefore, the WPT enables the extraction of features from the signals that combine the stationary and non-stationary characteristics with an arbitrary time-frequency resolution. Sun and Chang (2002) developed a WPT-based component energy technique for analyzing structural damage. The component energies were firstly calculated and then they were used as inputs into the neural network (NN) models for damage assessment.

In this paper, a WPT-based method is proposed for the damage detection of beam structures. Dynamic signals measured from structures are first decomposed into the wavelet packet components. The wavelet energy rate index is proposed, which is then used to locate damage. Both simulated and tested beams with