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Structure Damage Identification via Fiber Grating Strain Sensing Array Detecting and Wavelet Analysis

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Abstract

The measuring method of structure damage during vibrating has been developed by applying simple supported beam as object of study, fiber Bragg grating strain sensing array as the measuring method, and wavelet package analysis as signal extracting tools. The damage data of simple supported beam at vibrating state has been collected. The damage characteristic indexes have been extracted based on analyzing and handling the damage data with wavelet analysis. The experiment shows that fiber Bragg grating strain sensing array can sensitively measure the experimental data of simple supported beam at vibrating state. The fiber Bragg grating strain sensing array measuring is a new method in dynamic measurement.

Keywords

Fiber Grating Strain Sensing Array, Wavelet Package Analysis, Simple Supported Beam, Cracks Detecting, Vibration

1. Introduction

Damage identification of engineering structure will be realized by measuring signal to obtain structural state changes [1]. Beam structure is the primary component in the engineering structure and also basic component of different structure; it is the most general flexural structure in engineering application; it has been widely applied in the engineering field of machinery, traffic and architecture [2]. The key to the damage identification question which taking vibrant measuring data as basis is: to find a characteristic index or damage index that can response the structural state. Traditional signal analysis is based on the Fourier transform of the stable signal which can't express the time-frequency property of signal. However, in actual structural damage identification, most measuring signals are non-stable and need to be analyzed at frequency of local time. This is called by time-frequency analysis. The wavelet analysis and the wavelet package analysis have favorable localize property at the same time in time and frequency fields [3]. They can focus on arbitrary details of signal, and can easily realize time-frequency analysis of non-stable signal. In addition, the wavelet package analysis is still a finer time-frequency decomposition method and can treat the high frequency part which isn't subdivided in wavelet analysis.

Researchers have taken amount of research on measuring cracks with various measuring methods such as ultrasonic, rays, acoustic emission, liquid permeation coloring, synthetic crack detection method, magnetic powder, vortexing and microwaves. S. Caddemi, I. Calio & M. Marletta [4] have studied nonlinear dynamic response at state of beam cracking. A. Khorram, M. Rezaeian & F. Bakhtiari-Nejad [5] have studied multiple fractures damage detection under a moving load on the beam. Tang Tianguo, Liu Haowu, Chen Chunhua & Liu Xiaosen [6] have studied damage of beam by modal strain energy. Jiang Haibo & Zhao Renda [7] have studied vibration modal analysis on damage simple supported beam. Xu Ping [8] has studied curvature mode of damage simple supported beam. An Yonghui & Ou Jinping [9] have imitated and analyzed the simple supported beam bridge. However, these works have not realized long distance online monitoring due to electronic engineering sensors. Fiber Bragg grating sensing technology is a new type technology [10] [11] [12], which has many advantages such as little structure, convenient to use, immune to electromagnetics, easy to web forming, fitting to online monitoring, and conveying to long distance. At present, many types of fiber grating sensors have been applied to real-time monitoring scene.

In this paper, the fiber Bragg grating strain sensing array is adopted to measure vibration of simple supported beam. The wavelet package analysis is used to acquire vibrating data of simple supported beam structure. The dynamic analysis has taken on the damage data of beam structure. The real-time dynamic monitoring of simple supported beam has been realized.

2. Wavelet Package Analysis Method

Wavelet package is proposed by Wicherhauser *et al.* in 1989 based on wavelet transform. Wavelet package analysis is supplement of wavelet transform, which can provide complete resolution at different levels. Multi-resolution characteristic of wavelet can effectively resolve signal at time-frequency field. There is poor frequency resolution at high-frequency section and poor time resolution at low-frequency stage. Therefore, the wavelet package analysis can divide the frequency band of signal in index equal interval pattern. Multi-resolution analysis in fact is to resolve the general frequency band of the analyzed signal, and to further resolve low frequencies of each level resolving frequency band and wavelet transform. If the high frequencies of each level resolving frequency band are further resolved and be analyzed by wavelet method, the process is called as wavelet package analysis. The aim of the wavelet package analysis is to further resolve those non-subdivided high frequencies obtained by multi-resolution analysis. During the wavelet package analysis, choosing self-adaptively relevant frequency band according to characteristic of analyzed signal may realize well-matched frequency spectrum of signal, as a result, the resolution ratio will be greatly increased. Therefore, the wavelet package analysis is a finer time-frequency resolving method than the wavelet analysis.

Wavelet package is usually composed of linear combinations, which can provide a series of primary functions. Thus, it has the orthogonality and time-frequency local characteristic. One wavelet function $\psi_{j,k}^{i}(t)$ has 3 indexes, *i*, *j*, *k* indicate frequency, dimension, offset parameters of wavelet package function, respectively.

$$\psi_{j,k}^{i}(t)=2^{j/2}\psi_{i}\left(2^{j}t-k\right),\ i=1,2,3,\cdots \tag{1}$$

Wavelet function ψ_i can be solved by the following equation:

$$\begin{aligned}\phi^{i}(t)&=\sqrt{2}\sum_{k=-\infty}^{\infty}h(k)\phi^{1}(2t-k)\\ \psi^{i}(t)&=\sqrt{2}\sum_{k=-\infty}^{\infty}g(k)\phi^{1}(2t-k)\end{aligned} \tag{2}$$

where ϕ^i is dimension function, the primary wavelet function $\psi^i(t)$ is known as mother wavelet, that is:

$$\psi^{i}(t)=\psi(t) \tag{3}$$

The discreted filter coefficients $h(k)$ and $g(k)$ are the integral acoustic image filter coefficients related to the dimension function and mother wavelet function. The wavelet functions have the same orthogonality, time-frequency localization and so on as these of the corresponding wavelet package. Wavelet package analysis can map any signal onto a group of primary functions formed by wavelet stretching out and drawing back. In order to localize analysis for the non-steady signal, one need to obtain the decomposed array distributed among different frequency band within pass-band. However, the wavelet package energy spectrum is very sensitive to tiny damages of structure, tiny damages due to the very small changes in structural mass, stiffness and damp may cause large changes in energy spectrum. Therefore, the wavelet package method may analyze the response signals before and after structure damage. By comparing changes of energy of each stage sub-signal, one can construct indexes of damage and finish the structural damage identification.

3. Experimental Section

Vibration experiment carried on a simple supported beam with 500 mm in length, 70 mm in width, and 2 mm in height. An exciter is located in 250 mm away from non-crack tip of the beam. Four stainless-steel plates have been fabricated, which have no damage, one crack, two cracks, and three cracks, respectively. Fifteen gratings are pasted on each stainless-steel plate, as is shown in Figure 1. The paste length of fiber grating is about 20 mm. Fifteen gratings are divided into three groups and pasted into three arrays. For the first array the distance between the head end and the fixed one of beam is about 40 mm. The distance between the terminal of the first grating and the head end of the second grating is about 80 mm, and so on. The distance between the terminal of the fifth grating and another fixed end of the beam is about 40 mm. Other two groups are pasted according to the same pattern as that of the first array. Along the horizontal direction of the beam, the first array locates about 15 mm away from the horizontal side, the second one is pasted on center axis, and the third one is symmetrically pasted on another side.

Fifteen Bragg gratings are fiber Bragg gratings array being connected to an optical fiber. These gratings are divided into three groups and pasted on the surface of the beam. Before having carried out the pasted experiment, the surface of beam must be first cleaned by alcohol, and then marks a position for accurately pasting the fiber gratings. After having pasted by epoxy-resin glue, the steel plate must be placed quietly 24 hours. The vibration test can be done. Before collecting the experimental data, it needs to preload on beam. Namely, the beam is vibrated in an acceptable range, and each Bragg grating is in working condition.

Before experiments, the experimental equipment must be preheated for half an hour. In this experiment, the following equipment must be used; they are exciter, signal generator, power amplifier, fiber grating demodulator, and computer. Experimental process is shown in Figure 2.

4. Results and Discussion

The experimental process of measuring damage simple supported beam with fiber Bragg grating strain sensing array is as following: Firstly, it needs to excite the simple supported beam in turn in the range of 0 - 200 Hz at keeping unchangeable output voltage value of signal generator steadiness. Secondly, we

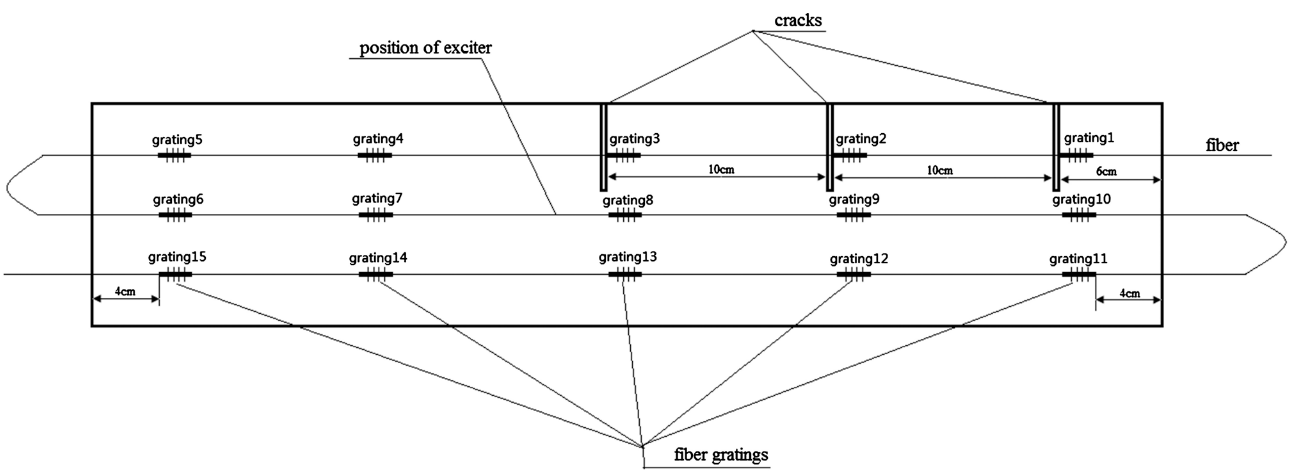

Figure 1. Experimental setup.

found that the collecting signals from the sensor are basically the normal sinusoidal signals in the range of 10 - 30 Hz, the wave form of signals are changed when the vibrating frequency is more than 30 Hz, and then there are to appear some additional sinusoidal wave signals. Thirdly, when the beam is in resonating state, the measuring signals still keep sinusoidal wave form function for the undamaged beam, are changed and appear many harmonic waves for those damaged beams. This phenomenon is attributed to additional nonlinear signals induced by the collision between the two end faces of cracks under the resonation condition. The experimental data of fiber Bragg grating strain sensing array collecting are collected and analyzed by data collector, and are demodulated by fiber grating demodulator. The wavelet package analysis of all the data has been completed by the wavelet package analysis soft in the collecting analyzer. The wavelet package analysis spectrum figures for these damaged simple supported beams are shown in **Figures 3-6**.

Figure 3 is the wavelet package analyzing figure of fiber Grating detecting vibration of undamaged simple supported beam. The engineer spectrums appear

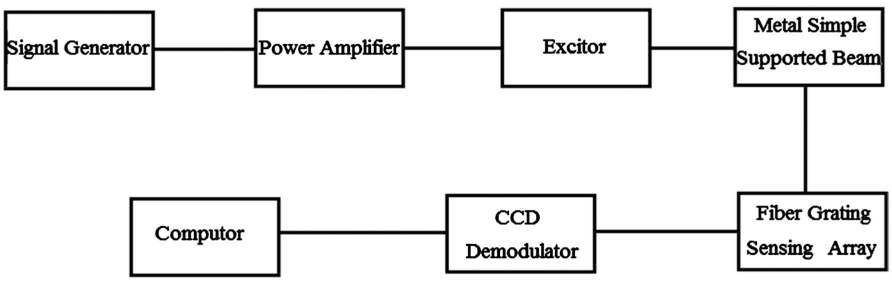

Figure 2. Experimental process.

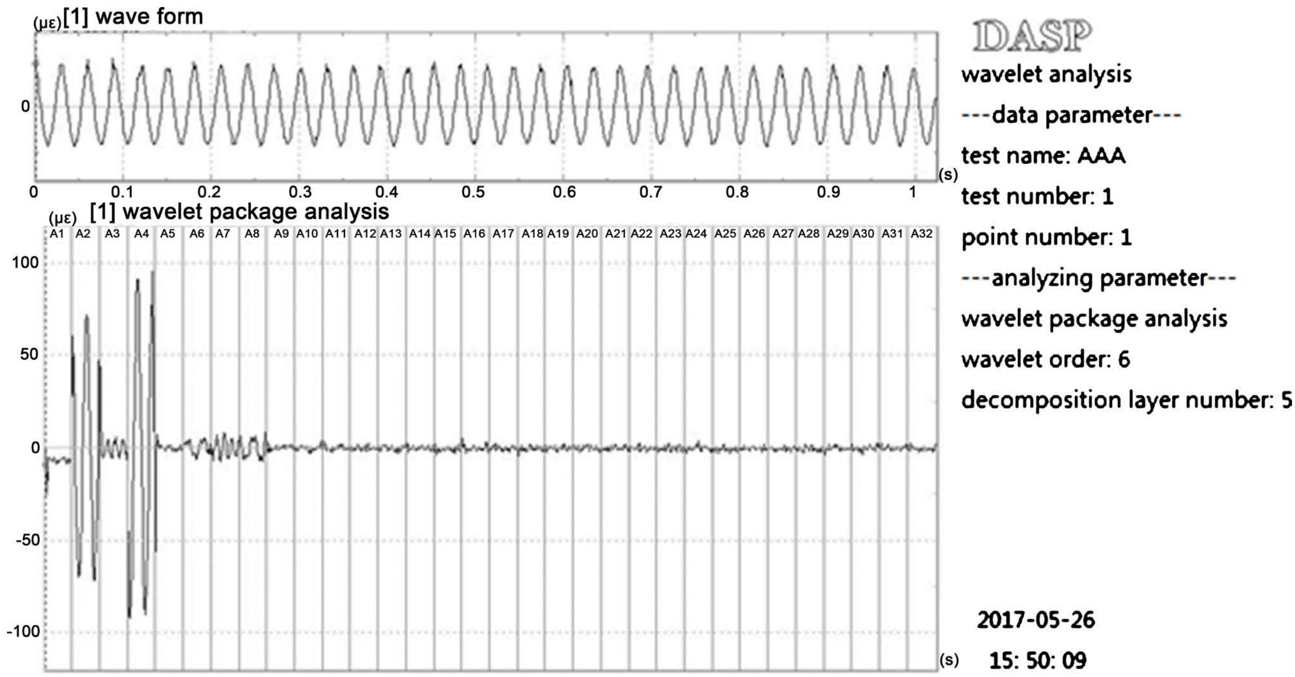

Figure 3. Wavelet package analysis diagram of undamaged simple supported beam at vibrating state.

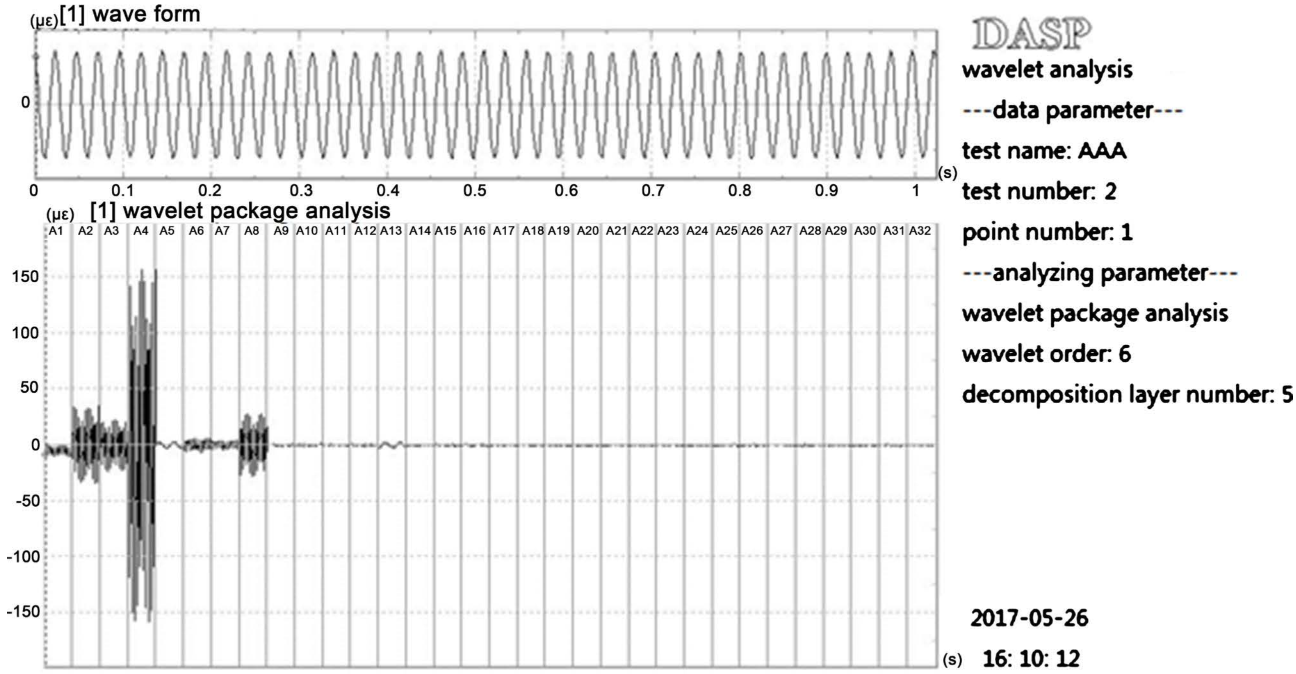

Figure 4. Wavelet package analysis diagram of one-crack simple supported beam at vibrating state.

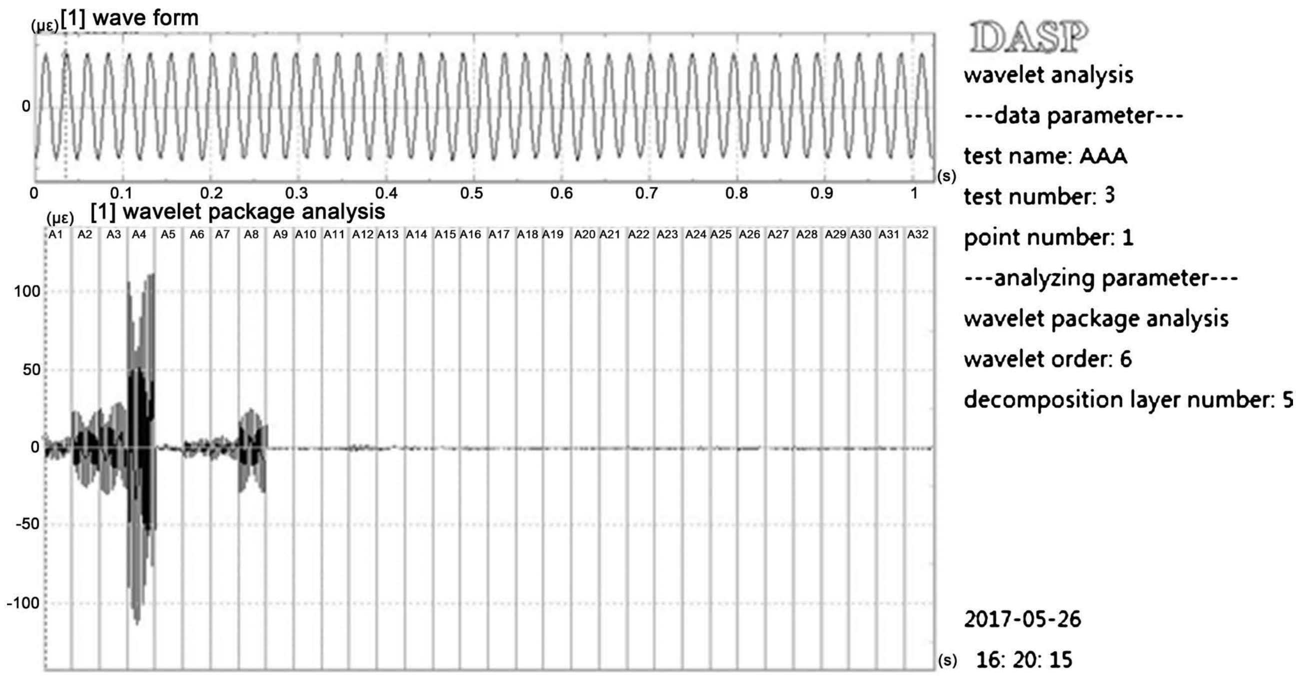

Figure 5. Wavelet package analysis diagram of two-crack simple supported beam at vibrating state.

at low-frequency stage. There is no engineer spectrum at high-frequency stage. Figure 4 is the wavelet package analyzing figure of fiber Grating detecting vibration of one-crack simple supported beam. Compared with undamaged signal, there is some different change. The engineer spectrum changes at A3 frequency band. Figure 5 shows the wavelet package analyzing figure of fiber Grating detecting vibration of two-crack simple supported beam. Compared with signal of

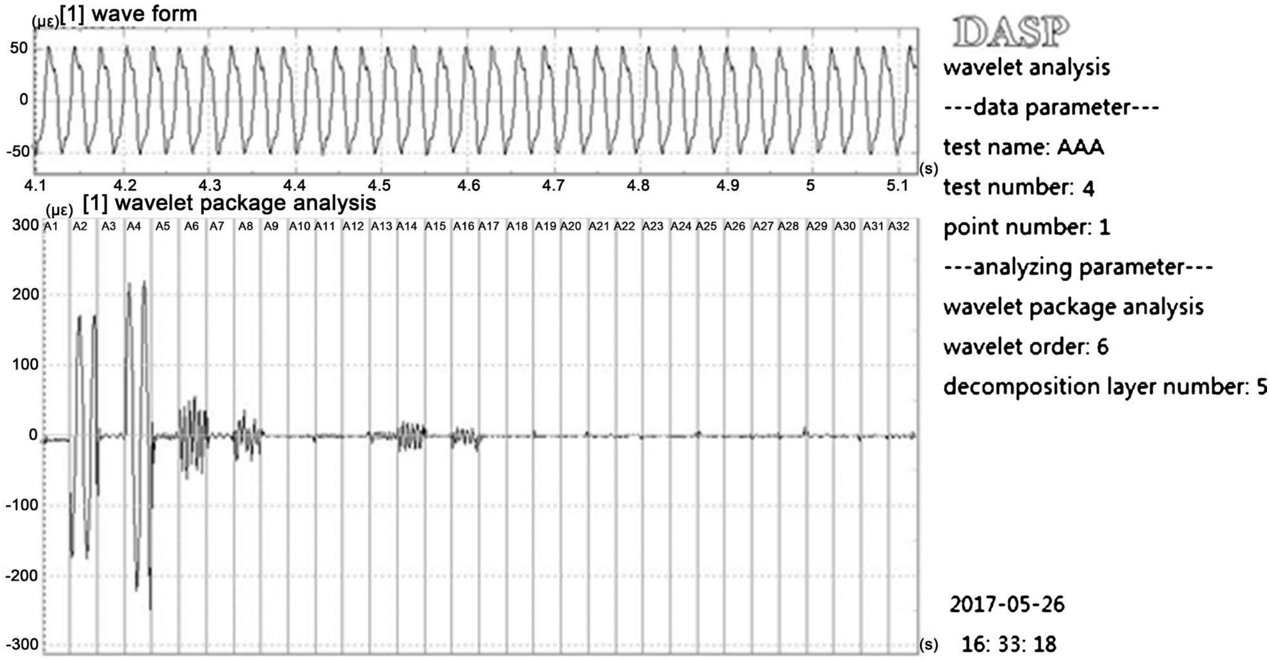

Figure 6. Wavelet package analysis diagram of three-crack simple supported beam at vibrating state.

one-crack, the engineer spectrums have obvious difference at A1, A2, A3, A6 and A7 frequency bands. Figure 6 shows the wavelet package analyzing figure of fiber Grating detecting vibration of three-crack simple supported beam. Compared with engineer spectrum analyzing figure of two-crack, the engineer spectrum figure change more at A1, A2, A3, A6, A7 and A8 frequency bands. There are engineer spectrums at A14, A16. This is possible that two beams of crack clap each other. The frequency spectrums at different frequency band will appear various changes as cracks are increasing. Therefore, the different damage states of simple supported beam can be decided according to different of energy index. Obviously, the energy indexes of wavelet package analysis are the strong basis to detect the tiny damages.

5. Conclusion

In this paper, the measuring method of structure damage during vibrating has been studied with simple supported beam as object of study, fiber Bragg grating strain sensing array as the measuring method, and wavelet package analysis as signal extracting tools. The damage data of simple supported beam at vibrating state has been collected. The damage indexes have been acquired after analyzing and handling the damage data. The experiment shows that fiber Bragg grating strain sensing array can sensitively measure the experimental data of simple supported beam at vibrating state. The fiber Bragg grating strain sensing array measuring is a new method in dynamic measurement.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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