

Research on Detection Method Based on Composite Excitation - Fiber Bragg Grating Sensing Technique

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Abstract. Traditional nondestructive assessments play a key role for condition monitoring of in-service structures. But in the actual condition, the structural response may be a superposition effect of vibration source interaction. The traditional detection methods only consider the main source, which would cause analysis error due to ignoring other vibration sources. Therefore, it is of practical engineering significance to study the detection method of compound excitation. The composite excitation method is applied to monitor the structural vibration response characteristics by applying different excitation sources. This paper proposed a new detection method of composite excitation based on fiber Bragg gratings sensing. A platform for experiments is built to verify the theoretical analysis of the sensing characterization of the fiber Bragg gratings sensor in composite excitation. Experiment results reveal the FBG sensing characteristics under composite excitation and provide experimental basis for further structural monitoring.

1. Introduction

Large machinery and equipments play a significant complimentary role in many fields, such as the aviation field, where the response characteristics of aircraft structures become complicated during service because of the complex operating environment. In the actual condition, the structural response may be a superposition effect of vibration source interaction, while the traditional detection methods only consider the main source, which would cause analysis error due to ignoring other vibration sources. Therefore, it is of practical engineering significance to study the detection method of compound excitation. The composite excitation method is applied to monitor the structural vibration response characteristics by applying different excitation sources, and it is gradually referenced by the scholars at home and abroad in the field of engineering structure monitoring.

The United States Missouri-Rolla University, Boeing and the Air Force Research Institute jointly proposed a hybrid fault detection technology based on ultrasonic and eddy current. Some scholars have tried compound detection technology research: Zhang Qinghua studied the mechanism and application of combined ultrasonic and Eddy current nondestructive testing [1]. Klepka studied damage detection in laminated composites by nonlinear vibration-acoustic modulation technique [2]. Ming Hong studied fatigue damage characterization by modeling nonlinearities of ultrasonic waves [3]. S Khatir studied damage detection and localization in beam structures by Genetic algorithm based objective functions [4]. Hiroshi Tsuda analysed damage detection in CFRP using fiber Bragg gratings [5]. Byeong Wook Jang analysed impact identification algorithm for composite structures using fiber Bragg grating sensors [6]. Aldo Baccigalup investigated Huang Hilbert Transform for evaluating the



instantaneous frequency evolution in non-linear systems by comparing the different traditional approaches [7]. H. Chouiyakh introduced Huang Hilbert transform, empirical mode decomposition and instantaneous frequencies into an accurate multicrack identification for a large number of cracks [8]. With the continuous attempts of composite detection and signal analysis methods, the composite detection method makes full use of the advantages of each detection technology, avoids the limitations of the single detection method, and gradually becomes a new direction in the field of detection.

Therefore, combining with the development trend of detection technology, this paper aims to present an FBG sensing system based on composite excitation for the board plates and the key contribution is to establish a detection method based on the composite excitation-FBG sensing system combining the advantages of fiber grating sensing with composite features and to provide certain technical support for the structural diagnosis of in service aviation equipment. This paper is structured as follows. Section 2 reviews the basic features of composite testing. Section 3 is devoted to the characteristics of the composite signal by simulation. In Section 4, the basic experimental system is built, and the experiment results show that the combination of frequency parameters have great influence on the output response curve. Section 5 summarizes the full text.

2. Theoretical basis of compound excitation

The dynamic equation of composite excitation under low frequency vibration can be expressed as follows:

$$M\ddot{y}(t) + R\dot{y}(t) + Ky(t) = F \quad (1)$$

Here, k represents a stiffness matrix, R represents a damping matrix, and M represents the quality matrix. y represents the response of the displacement vector matrix; \dot{y} , \ddot{y} are expressed as a velocity vector matrix and an acceleration vector matrix, respectively; F represents an external input signal, which can be regarded as a linear superposition of natural vibration mode as force output signal, namely:

$$y(t) = q_1\{\phi_1\} + q_2\{\phi_2\} + \dots + q_n\{\phi_n\} = \sum_{r=1}^n q_r\{\phi_r\} \quad (2)$$

where q_r represent a modal coordinate vector, ϕ_r represents the mode shape of the first mode.

Substituting equation (2) into equation (1):

$$y(t) = q_1\{\phi_1\} + q_2\{\phi_2\} + \dots + q_n\{\phi_n\} = \sum_{r=1}^n q_r\{\phi_r\} \quad (3)$$

When the model is used to analyze the composite excitation system, the linear time-invariant characteristic is adopted. But the actual model has certain non-linear characteristic, in addition, various recursive algorithm need to select initial value and predict that basis of the system in advance. Therefore, the accuracy of the solution is affected. While the frequency response function may not require too many pre-determined parameters and its computational complexity is lower than that of time domain model analysis, so it is more suitable for the actual situation of compound excitation test system.

In the absence of noise interference, a frequency response function representing the relationship between the excitation signal and the response signal is established as follows:

$$Y_0(w) = H(w)F(w) \quad (4)$$

In practice, the signal may contain noise interference, resulting in a deviation in the frequency response function.

3. Response simulation under compound excitation

The frequency range of the vibration sources is within 20 kHz. Assuming that the two low-frequency vibration signals, sine waves, are x_1 , x_2 with the amplitude 50 V respectively. According to the compound vibration excitation theory, the signal frequency detected by the fiber grating is consistent

with the excitation frequency. It is assumed here that the attenuation coefficient of the amplitude is 10. Then according to the transmission characteristics in the system, it is known that the amplitude multiple is reduced by 10 times, and the frequency is consistent. So the amplitude of the signal detected by the corresponding fiber grating is 5V, the frequency is consistent with the excitation signal. The common effect under the excitation of the two vibration sources is shown in Fig. 1: Fig. 1(a) shows the output response effect when the excitation frequencies are 10.5 kHz and 2 kHz, respectively; Fig. 1(b) shows the output response effect when the excitation signal frequencies are 10.5 kHz and 9 kHz, respectively.

As can be seen from fig. 1(a), the low-frequency vibration signal is superimposed with the high-frequency signal to generate a sawtooth sine signal, but the general trend shows the vibration characteristics of the low-frequency signal. If we change the frequency of vibration in the simulation process, the effect is similar to the above, as long as it is a superposition of low-frequency signal and high-frequency signal. In fig. 1(b), when the two vibration signals are superimposed, an obvious beat phenomenon will occur, which is mainly due to the close frequency and the interaction of two signals.

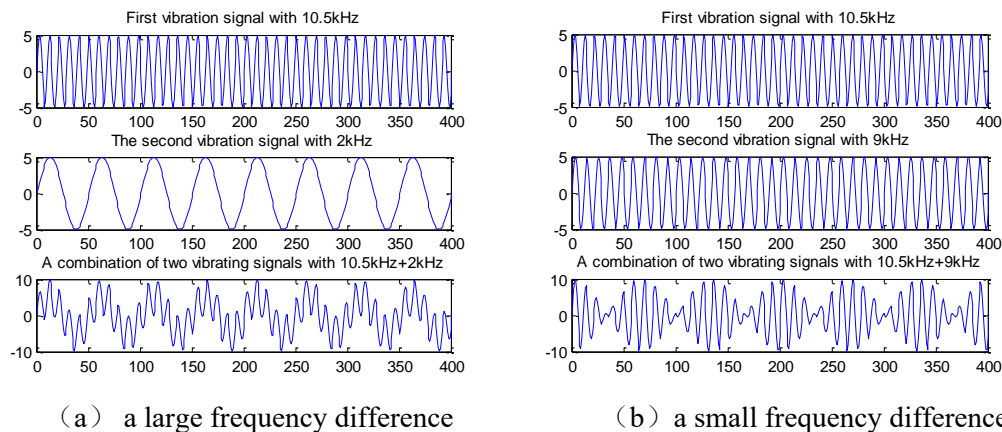


Fig. 1 vibration response simulation under different frequency combinations

According to the simulation analysis, we find the following characteristics of compound excitation: When the two harmonic frequencies are close to each other, a more complex vibration beat phenomenon will occur. In order to avoid the coupling phenomenon between two vibration sources with small frequency difference, we should choose the excitation combination with a slightly longer frequency distance. When the frequency multiples are different by at least 5 times, the coupling effect is weak. In this way, the whole change rule can reflect the change rule of the low frequency component. In order to avoid coupling, the same frequency can also be directly selected, which facilitates the analysis of multiple vibration source excitation detection signals.

4. Experimental verification of compound excitation - Fiber Bragg Grating Sensing

In order to verify the output response characteristics under the composite vibration excitation. The thin aluminum plate structure is taken as an experimental object, and two vibration excitations are applied to the piezoelectric sheets. The response signals of the board structure are picked up by the FBG sensors, whose demodulation system is included by laser source, coupler, photoelectric converter and digital oscilloscope. The experimental scheme is shown in fig. 2. Types of tunable laser source is Santec-TSL-510, photoelectric detector is Thorlabs-PDA-10CS, and digital oscilloscope is RIGOL-DS1102E respectively. In Fig.2, the plate size was 400 mm x 400 mm x 1 mm, and PZT1 represents piezoelectric sheet with a diameter of 10 mm, while PZT2 represents piezoelectric sheet with a diameter of 20 mm. FBG represents a fiber Bragg grating with a central wavelength of 1305.450 nm. Here the influence of the frequency parameters of the excitation signals are mainly discussed, whose experiment results is shown in figure 3.

Here two vibration signals are applied to piezoelectric sheets PZT2, PZT1, with the amplitude 5V. And the frequency of PZT2 is applied at a frequency of 10.5 kHz, while the frequency f_D of PZT1 is changed by 10.4, 10.9, 9 kHz, and the results are shown in figure 3. As can be seen from figure 3, the smaller the frequency difference between the two signals, the greater the cycle period. Conversely, if the frequency difference is greater, the cycle period is smaller. This phenomenon is consistent with the preceding theoretical analysis. Next, we analyze the experimental signal by Hilbert transform and get the envelope spectrum as shown in figure 4.

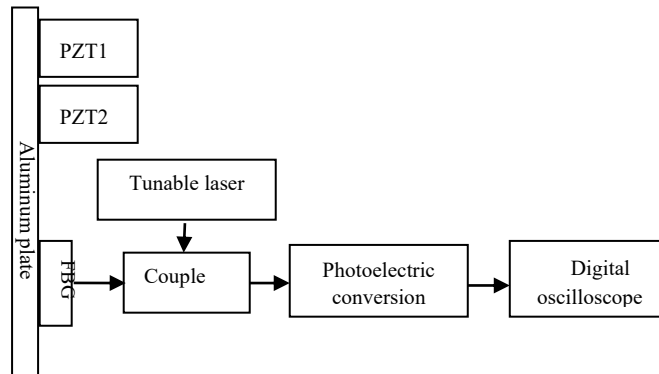


Figure 2. Composite vibration excitation based on FBG sensors

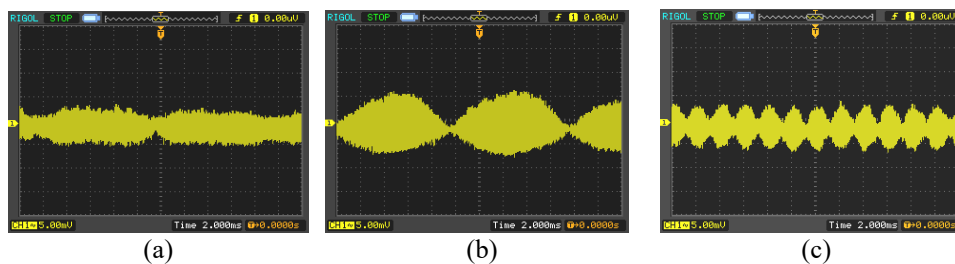


Figure 3. Vibration responses under varying frequency combinations

(a) $f_D=10.4$ kHz; (b) $f_D=10.9$ kHz; (c) $f_D=9$ kHz

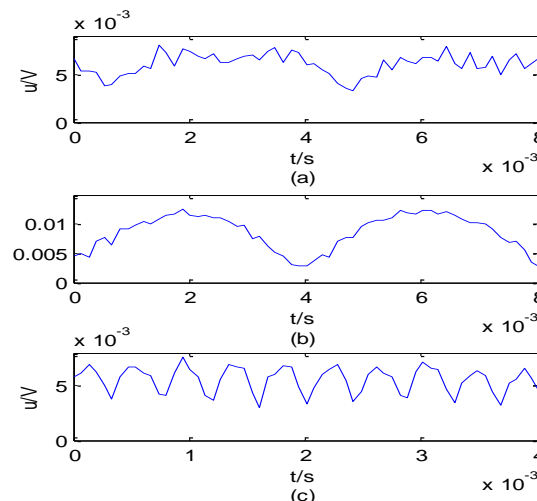


Figure 4. Response package of different combination motivation
(a) 10.5kHz+10.4 kHz; (b) 10.5kHz+10.9 kHz; (c) 10.5kHz+9 kHz

As can be seen from figure 4, we can see the following phenomena: the smaller the frequency difference between the two excitation signals, the greater the frequency cycle. Conversely, if the frequency difference is greater, the cycle period is smaller. In addition, signal noise also has an effect

on the envelope spectrum. In Figure 4(a), due to noise signals, in the envelopment spectrum, there are other components with 6.25 kHz and 2 kHz frequency besides two vibration signal sources. While in figures 4(b) and 4(b), the noise signal is small, so the envelopment spectrum consists of two vibration signal sources, and other clutter components can be ignored. From the envelopment waveform, we can see that the envelopment line with Hilbert transform is close to the contour of the output waveform.

5. Conclusion

This work focuses on the composite excitation-FBG sensing technology, different from the conventional approaches. In this paper, taking the board structure as the object, a detection system of composite excitation -FBG sensing technology has been given. First, the transfer characteristics under composite excitation are analyzed. Second, the characteristics of the composite signal by simulation are studied. Third, the experimental system based on composite excitation-fiber Bragg grating detection is built to verify the theoretical analysis of the FBG sensor and the experiment results show that the combination of frequency parameters has great influence on the output response, and the Hilbert transform can extract multiple source signals, which can provide experimental basis for further structural monitoring.

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