The Simulated Distortion Spectrum on Aluminum Alloy Structure with the Fatigue Crack Propagation

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Abstract. Fiber Bragg Grating (FBG) is expected to be a means of real-time monitoring of crack damage at the edge of the hole due to the sensitive perception of strain. In this paper, an optical fiber fatigue monitoring test platform is built for real-time monitoring of hole edge crack damage. Experimental results found that the grating could be sensed the strain variation with the crack propagation, caused by crack singularity, and the spectrum is highly correlated with the crack length. Full width at half maximum (FWHM) is a type of damage feature extracted from the simulated distortion spectrum, which has a high correlation with crack propagation. Meanwhile, the signal processing technique is used for the FWHM extraction, and the spectrum simulation, combined transfer matrix method and the finite element method, is investigated in this paper. The results show that the FWHM broadened obviously with the crack length, and the FWHM can be used as an effective index for evaluating fatigue crack growth.

1. Introduction
Fiber Bragg grating sensors in structural health monitoring (SHM) system has shown giant development space [1]. The FBG sensor has the characteristics of multiplexing and small size, etc. And it has been widely used in strain monitoring of nuclear power stations and large dams [2-4]. Simultaneously, the change of the physical properties of the composite structure is studied deeply because of the non-uniform strain distribution along the grating caused by the crack or layer damage in the composite structure [5]. However, the application of FBG sensor in crack damage detection of aluminum structure is a challenge all the time.

FBG sensors have been deliberately placed in non-uniform strain fields by some researchers [6], and the FBG sensors had been used for the composite health monitoring. In order to locate micro-cracks and delamination in the composite structure, the composite structure is embedded into bridging fibers [7]. Meanwhile, the spectrum width demonstrated a high correspondence with the crack density. Rajabzadeh [8] uses spectral bandwidth to measure the damage accumulation degree of composites quantitatively. However, few experimental researches have studied the use of FBG sensors adhered on the aluminum plates for the crack propagation. Jin [9] researched the crack propagation on the metal plate corresponding to the experimental spectrum change of the FBG sensor, and found that the spectrum is completely distorted, such as the emergence of multi-peaks in the distorted spectrum.

In this paper, we extracted FWHM damage characteristic by the peak seek algorithm, and the deeply relationship between the FWHM with the crack length was further researched.
First, the spectral reconstruction algorithm method was given. Because of the mechanical and optical inhomogeneity in the grating, the non-uniform strain cannot be reconstructed directly under uniform strain condition.

Cięszczyk [10] given the mathematical optimization model constrained by the main wavelength and spectral region, and estimated the shape of the strip. But these similarly technologies for the optical parameter extraction were usually costly.

Under non-uniform strain conditions, Jenkins and Joyce indicate that the transfer matrix method is a good way to predict spectral [11].

The paper shows that spectral reconstruction is realized, and TMM which is a numerical method is combined with the finite element model (FEM). After that, according to the spectral analysis, the corresponding damage feature extraction methods are put forward.

2. Finite Element Method Model
In order to analyze the crack growth problem, it is combined with structural health monitoring technique. The FEM of aluminum alloy specimen was founded by using commercial software ANSYS. Moreover, the strain got under different crack lengths was monitored by finite element model, and the strain value along the grating is obtained. They are shown in Figure 1.

![Figure 1. Strain distribution along the grating versus crack length](image)

3. The spectral simulation
The results show that the strain pattern is distributed near the crack tip and is completely non-uniform. In our previous studies, when the tip of the crack passes through the grating, the spectrum will be distorted. In addition, the relationship between the whole length of grating and the spectrum of inhomogeneous strain images during fatigue crack growth is also studied. By combining the finite element method with the TMM method, the spectrum simulation method is proposed.

The strain distribution along the grating is obtained by finite element analysis using commercial software ANSYS. In the numerical spectrum reconstruction method TMM, the calculated strain pattern is introduced and the FBG spectrum intensity is obtained. Figure 2 shows the structure of the spectral simulation algorithm.
The spectral changes corresponding to crack propagation are illustrated by spectrum simulation method. Firstly, FEM is carried out to better understand the strain distribution in the process of crack propagation. In addition, the strain value along the grating is synthesized into an equation which is in good agreement with the crack growth. Figure 3 shows the spectrum distortion in various strain distribution.

(a) The spectra under quadratic strain pattern

(b) The spectra under cubic strain pattern

Figure 2. FBG spectrum simulation algorithm structure

Figure 3. FBG spectrum under difference strain pattern
4. FWHM extraction algorithm
It is apparently that the strain distributed is completely non-uniform near the crack tip. At the same
time, because of crack propagation, the structure shows the nonlinear behavior in the dynamic spectral
response. What is more, the FWHM changes with the crack propagation. And in this paper, the peak
search algorithm is used to search the main wavelength. Then, we choose the -3dB spectral bandwidth
as FWHM. A schematic diagram is shown as shown in Figure. 4.

5. Results
In the monitoring of bridge structure, the research of FBG sensor for uniform axial strain sensing has
been fully studied. The measurement principle is based only on the displacement of the Bragg peak
reflected by the grating. But, the non-uniform strain form in front of crack singularity will lead to
spectrum distortion when the crack growth is detected by FBG sensing.

The paper shows that we get and analyze the simulated spectra which are extracted from FEM and
subjected to different strain modes. Simultaneously, based on peak search algorithm and box counting
method, crack damage feature extraction method is applied to the analysis of experimental and
simulated data. The FWHM damage characteristics of the simulated spectra caused by fatigue crack
damage is analyzed. The fatigue crack damage can cause the change of the damage characteristics.
And the paper analyzed the FWHM damage characteristics of the experimental and simulated spectra.

The results illustrate that the axial strain distribution and crack propagation of aluminum can be
monitored by the FBG sensor. At the beginning of the crack propagation, because of strain changes,
the small wavelength shift of the spectrum occurs. In the reflected wave, the spectrum is symmetrical
with the uniform wavelength shift. When the crack length increases, the strain gradient of non-uniform
along the grating gradually increases.

In contrast, On the contrary, due to the crack propagation into the grating region, FWHM is
sensitive to the compression field strain field in front of the crack tip. In this study, FWHM also has an
evident correlation with the crack length, in addition to achieving the saturation length of the crack.
Figure. 5 shows the relationship between FWHM variation and crack length under simulated damage
conditions.
6. Discussion
There are several forms of strain distribution near the crack singularity, so in the spectrum shape the non-uniform strain field produces the change (i.e. spectrum distortion). Moreover the number of peak splitting increases with the crack through the grating area. At the same time, as in our previous research, the sub peak position detected by grating is in the form of strain.

7. Conclusion
With the strain sensitivity of FBG, the FBG experimental platform is established for monitoring the crack propagation in this paper. And the FBG spectrum changes obviously with the crack propagation, especially the FWHM broadened with the crack length. Meanwhile, the spectra simulation approach is applied for the FWHM extraction, combined with the help of peak seek algorithm. The results show that the FWHM can be used as an effective index for evaluating fatigue crack growth.

8. References
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