Study on damage defection for complex thin-walled Structure by Lamb wave

Cai Li1,*, Zuo Xiaoqiong1, Jia Jianping1

1School of Mechanical and Electronic Engineering, Wuhan Donghu University
*20204268@qq.com

Abstract. In this paper, Lamb wave detection technology is applied in damage detection of complex thin-walled structure by fiber Bragg grating (FBG) sensor, and the detection characteristic of Lamb wave is analyzed for complex thin-walled Structure. Then on this basis, the FBG experiment system is set up with different excitation parameters. The experimental results show that Lamb wave is sensitive to material and stratification by analyzing the interaction between Lamb waves and defects, which can provide experimental basis for experimental basis in further damage defection.

1. Introduction

Traditional structural damage detection methods have been widely used in various fields, including ultrasonic testing, eddy current detection, ray flaw detection and visual inspection. Among them, the ultrasonic detection technology has many advantages: fast speed, high sensitivity, low cost, harmless to the human body, which is widely used in many fields of aerospace, machinery, materials, ocean exploration, medical diagnosis and other fields [1]. Lamb wave detection is one of the methods of ultrasonic detection. Lamb wave is very sensitive to small subsurface defects, and it can be transmitted at a long distance in the flat structure, so it is widely applied in structural damage detection [2]. However, Lamb wave propagation theory is very complex., because Lamb wave mode produces other mode waveforms by interacting with defects or by crossing different boundaries. Signal extraction and analysis is more complex. So it is very necessary to research the the propagation of Lamb wave.

In recent years, fiber Prague grating sensing has gradually become a new sensing element, which overcomes the shortcomings of traditional electronic sensors [3]. Hiroshi Tsuda carried out the damage detection research of carbon fiber composites, and proved the possibility of damage detection by using FBG sensor [4]. Jang, Byeong-Wook used multiplexed fiber Bragg grating sensor to study damage detection for composite structures [5-6]. Daniel C Betz described a new Lamb wave detection based on the Prague fiber Bragg grating sensor [7]. Thus it can be seen that fiber Bragg grating can be applied to the Lamb wave detection.

Aiming at the application of fiber grating sensing Lamb wave detection, this paper studies the response characteristics of FBG sensors under different parameters, and proposes a lamb wave detection based on FBG sensing system. This paper demonstrates a new detection method using fiber Bragg grating sensors for the complex thin-walled structure. The text of this article begins in section 2 with the basic principle of Lamb wave propagation, which is essential for the damage detection. Section 3 introduces the characteristics of fiber Bragg grating sensors, which is sensitive element for detecting Lamb wave. Then section 4 describes the experimental system. We compare the responses of fiber Bragg grating sensor signals under different excitation parameters, and analyze the response
characteristics under different damage conditions. And the results show Lamb wave detection is affected not only by materials, defects, but also by the interaction between Lamb waves and defects through the analysis of the interactive features.

2. Theory of Lamb wave propagation and FBG sensing

2.1. Propagation principle of Lamb wave.
Damage detection mainly depends on the appropriate methodology or strategy of monitoring. In order to understand the framework of the detection system, we first introduce the physics principle of Lamb wave propagation.

The Lamb wave detection is one of the forms of ultrasonic detection, which is an elastic wave produced by the interaction of longitudinal and transverse waves in two parallel plane thin wall structures. The propagation of elastic wave in thin walled structure is Lamb wave. When Lamb wave meets an internal defect, one part of Lamb wave will be reflected. We can realize the detection of damage localization based on Lamb wave reflection signal analysis.

In the active detection of Lamb wave, the selection of excitation signals is usually taken into consideration in several aspects, such as excitation, central frequency, excitation amplitude and so on. There are three main modes of Lamb wave excitation: ultrasonic transducer, piezoceramic, polyvinylidene fluoride. In this paper, the ultrasonic probe is used to select the first method, and the coupling agent is used to transmit ultrasonic wave to the thin wall structure. The Lamb wave model can produce a variety of other patterns by interacting with defects or crossing the different boundaries.

Ultrasonic probe is easier to control the incident angle and amplitude parameters. When Lamb wave frequency is low, the signal propagation mainly contains two modes of A0 or S0; on the contrary, when the center frequency is high, Lamb wave propagation model is more complex, which is not conducive to the detection of damage signal. Therefore, it is very important to select the central frequency of the Lamb wave testing. Generally speaking, the propagation of ultrasonic wave in materials is very small, which is usually only tens or more than a dozen microstrains, so the appropriate choice of excitation amplitude parameters is also crucial.

2.2. Features of FBG.
Fiber Bragg grating (FBG) is a periodic disturbance of the refractive index, which has the characteristic of reflected light in a predetermined wavelength range centered around a peak wavelength value. The Bragg wavelength \( \lambda_B \) is given as follows:

\[
\lambda_B = 2 \Lambda \bar{n}_{eff}
\]

where \( \Lambda \) is the grating period and \( \bar{n}_{eff} \) is the mean effective refractive index in the grating region. The demodulation method is then used by using a narrow linewidth laser. If the wavelength of the laser is matched to a part of the grating spectrum, any displacement of the spectrum will modulate the reflected light power. The use of a tunable laser source allows the interrogation of several gratings within a single fiber line.

The fiber Bragg grating demodulation system needs high demodulation speed to measure the ultrasonic signal. In addition, the optical fiber grating has an axial strain sensitivity, while the ultrasonic energy is focused on the acoustic axis. In the far field, the sound pressure on the axis is reduced with the increase of the distance. These conclusions can be obtained in the later experiment.

3. Detection test of lamb wave using FBG

3.1. Propagation principle of Lamb wave.
When the thickness of complex thin-walled structures is uniform and the length is much greater than the thickness, the detection characteristics are similar to those of plate propagation.
Based on the above principles, the damage detection of Lanmubo was carried out using fiber Bragg grating sensing technology, as shown in Figure 1. The distance from the ultrasonic probe is about 100 mm, and the Lamb wave signal is transmitted through a coupling to a complex thin-walled structure. The center wavelengths of the FBGs were 1303nm and the center frequency of ultrasonic probe was 1MHz with the 30° angle. Demodulation system demodulates the fiber Bragg grating reflection wavelength, which will display on digital oscilloscope screen after the photoelectric conversion, which is adjusted to 10dB.

When the fiber Bragg grating is on the same horizontal line of ultrasonic axis, the peak value of the fiber grating is the highest because of the high sensitivity of the axial strain of the fiber Bragg grating. In the far field, the sound pressure on the axis decreases with the increase of distance. This phenomenon can be seen from Figure 2: the maximum peak value of the output response is 253.2mv when the fiber Bragg grating has no angle with the ultrasonic acoustic axis. When the angle is 30 degrees, the peak value of the output response is rapidly reduced to 108.7mv; when the angle is 90 degrees, the minimum peak value of the output response is only 34.9mv. Therefore, the angle has a great influence on the amplitude of the response. The output response peak of VPP significantly reduces the excitation direction angle. In order to obtain better signal, the angle of ultrasonic radiation should be less than 30 degrees.

Figure 3 shows the response waveform of the fiber Bragg grating under the damage of different sizes. The greater the diameter of the damaged hole, the smaller the peak response of FBG. When there is no damage in the structure, the maximum peak value of output response is 120mV. When the diameter of the hole is 4mm, the peak value of the output response falls to 50mV rapidly. When the diameter of the hole is 12mm, the peak value of the output response is only 20mV. Therefore, the response amplitude is greatly influenced by the size of the damage, too.
3.2. Damage detection of Lamb wave using FBG

According to the above experimental results, the layout design of FBG and the size of the thin-walled structure are shown in Figure 4. There are three FBG sensors in the board on A, B, and C points. B is attached to the horizontal direction of the acoustic axis and it is 100mm at the center distance from the ultrasonic probe. The other two fiber Bragg grating sensors, A, and C are arranged in a vertical line of the sound axis, which keeps the distance 50mm with B, respectively. The ultrasonic probe and the middle FBG distance are 100mm, thus ensuring that the excitation angle is less than 30 degrees.

Fig.4 FBG layout and the thin-walled structure dimension

The excitation is applied to the position "delta" by the ultrasonic probe, and the waveforms detected by the fiber Bragg grating are shown in Figure 5. As can be seen from the diagram, the FBG detection signal at the B point is the highest on the shaft of the ultrasonic, as shown in figure 5b: the first peak of the output response wave at point B is about 128mV, and the second peak value is 96mV. While the first peak of the output response wave at point A or C is about 84mV, and the second peak value is 32mV. It can be seen that the response amplitude of FBG is greatly influenced by the angle, and the output response is basically the same under the same direction angle, such as two fiber Bragg grating sensors, A and C.

As seen in Figure 6, the signal of the sensor B is compared and analyzed in a healthy or damaged thin wall structure. According to the time difference of wave propagation, the distance between the actual distance and the excitation point can be calculated. It is obvious that signal processing is very important, otherwise, due to the interference of the clutter signal, the large measurement error will be produced.
4. Conclusion
In this paper, a method of Lamb wave detection based on fiber Bragg grating sensing is proposed, and the corresponding experimental system is set up. In this paper, the basic characteristics of the FBG responses are analyzed and verified for detecting Lamb wave. Then an experimental system for complex thin-walled structures is established. By analyzing the interaction between Lamb waves and defects, Lamb waves are sensitive to complex thin-walled structures. The principle of wave propagation parameters is selected, which provides important references for subsequent damage location analysis.

Acknowledgment
This paper is funded and supported by the Science Research Project of Hubei Province Education Department (No. B2017298) and the youth natural science fund of Wuhan Donghu University (2016).

References
[1] Costiner, Sorin; Winston, Howard A. Optimal FBG sensor placement in composite components: Algorithm and sensor type trade studies. Source: Annual Forum Proceedings-AHS International. 2011, vol.3: 1627-1643.
[2] B C Lee and W J Staszewski. Modelling of Lamb waves for damage detection in metallic structures: Part I. Wave propagation. Smart Materials and Structures. 2003, vol.12: 804-814.
[3] Alan D. Kersey, Hiroshi Tsuda, Kenji Kumakura, Shinji Oghara, Ultrasonic sensitivity of strain-insensitive fiber Bragg grating sensors and evaluation of ultrasound-induced strain, Sensors. 2010, vol.10: 11248-11258.
[4] H. Tsuda, N. Toyama, J. Takatsubo. Smart Structure Research Center, AIST, AIST Tsukuba. Damage detection of CFRP using fiber Bragg gratings. Journal of Materials Science. 2004, vol.39: 2211-2214.
[5] Jang, Byeong-wook; Park, Sang-oh; Lee, Yeon-gwan. Detection of impact damage in composite structures using high speed FBG interrogator. Source: Advanced Composite Materials. 2012,21(1): 29-44.
[6] Jang, Byeong-wook; Lee, Yeon-gwan; Kim, Jin-hyuk. Real-time impact identification algorithm for composite structures using fiber Bragg grating sensors. Source: Structural Control and Health Monitoring. 2012, 19(7): 580-591.
[7] Daniel C Betz, Graham Thursby, Brian Culshaw and Wieslaw J Staszewski. Acousto-ultrasonic sensing using fiber Bragg gratings. Smart Materials and Structures. 2003, vol.12: 122-128.