

System of ultrasonic non-destructive testing of carbon fiber composite defects

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In this article a non-destructive detection software system was firstly established using LabView and MATLAB and then a test was carried out on the application of the software system in ultrasonic non-destructive detection to verify its adaptability in detection of defects of carbon fibre composite and analyze the advantages and limitations of the detection system.

Key words: Ultrasonic non-destructive detection system; carbon fibre composite; application; perfection

Впервые внедрена система неразрушающего контроля, использующая LabView и MATLAB. Проведена проверка ее применения при ультразвуковом неразрушающем контроле дефектов композита из углеродного волокна. Проведен анализ преимуществ и ограничений применения.

Система ультразвукового неруйнівного контролю дефектів композиту з вуглецевого волокна. *Xuerui Wang, Yan Zhou.*

Вперше впроваджена система неруйнівного контролю, що використовує LabView і MATLAB. Проведена перевірка її застосування при ультразвуковому неруйнівному контролі дефектів композиту з вуглецевого волокна. Проведено аналіз переваг і обмежень застосування.

1. Introduction

Carbon fibre composite as an advanced composite has been extensively applied in high-edge technical fields such as spaceflight, aviation and military affairs for favorable properties such as light weight and high strength. Moreover it develops rapidly in fields of building materials, chemical engineering and medical devices [1]. Carbon fibre material has wide application, but it has inevitable defects in the process of production and use [2].

Huang [3] proposed a three-dimensional digital model motivated ultrasonic C scanning technology for aircraft composite materials. Backe D et al. [4] developed a novel ultrasonic

detection equipment and investigated the performance of carbon fiber reinforced polymer using online non-destructive test, Hosseini S [5] studied the ultrasonic filed in heterogeneous composite, compared the theoretical prediction results with the simulation results obtained by CIVA, developed and verified a novel non-destructive detection system, and proposed suggestions for the optimization of ultrasonic detection system.

This study aims at verifying the adaptability of ultrasonic non-destructive detection system and ultrasonic non-destructive detection system based on experiments and defects of carbon fibre composite and moreover proposing some constructive suggestions for the system.

Table 1 Categories of main defects of carbon fibre composite

Categories of main defects	Description of defects	Effects on composite
Void	Partial space inside carbon fibre composite is occupied by air; the cavities caused by the occupation by air are called voids.	Voids may reduce the bearing surface and carrying capacity. Void is a stress concentration point. The higher the stress concentration coefficient, the more obvious the stress concentration. It can result in decrease of apparent property [7].
Rich resin	Area in which local content of resin is obviously higher than the average content of resin in workpiece of composite material [8]	Severe rich resin means reduced carrying capability of the composite.
Layering	Large-area space caused by cracking between layers [9]	Layering defect may reduce the strength of the composite and finally damage the overall structure.
Inclusion	Existence of impurities	High content of impurities in the composite may severely affect the physical performance.
Rarefaction	Existence of many pores	It may reduce the strength of material.

The categories and characteristics of defects of carbon fibre composite was accurately analyzed, which could guide the selection of proper ultrasonic detection technologies and the formulation of ultrasonic signal processing scheme and effectively enhance the accuracy and reliability of identification of defects of carbon fibre composite [6]. Table 1 shows the categories of main defects of carbon fibre composite.

Ultrasonic non-destructive detection

Ultrasonic detection methods can be divided into two categories, i.e. pulse transmission method and pulse reflection method [10].

Pulse reflection method which is frequently used refers to launching ultrasonic wave pulse according to certain frequency and interval and then displaying the defect detection results on an optical screen in form of reflective pulse signals. The defects inside materials can be evaluated through analyzing reflection echo.

Ultrasonic penetration method refers to installing ultrasonic probes on two relative sides of a material. When there were no defects, the obstacle of ultrasonic wave transmission is small and receiver probes can receive strong sound wave; when there were defects, ultrasonic wave will be inhibited in the process of transmission and the sound wave received by receiver probes is weak. Based on the characteristic, the existence of defects inside materials can be determined according to the energy of received sound wave.

Time-frequency signal analysis

Received signals are able to reflect the response of composites to sound wave after processing by amplification and smoothing, and detailed analysis can be performed.

Short-time Fourier transform (STFT) [11] and wavelet transform are the common methods in time-frequency analysis.

For any signal $x(t)$, if a signal is stable in a window function whose time center was r , then

$$X_{STFT}(r, \omega) = \int x(t)g(t-r)e^{-j\omega t} dt$$

There are two variables in STFT, indicating window function is the common function of time and frequency. Such a characteristic of window function makes STFT obtain the frequency spectrum at time r . The frequency spectrum of signals can be acquired if time was continuous; moreover the frequency spectrum changes with time. It should be noted that the shape and width of window function can affect the time-frequency resolution of STFT, and the time-frequency resolution of STFT only depends on window function $g(t)$. For any (r, ω) , the time-frequency resolution is the same.

Wavelet transform can effectively solve the problem of the adaptability of time-frequency resolution in non-stationary signal analysis [12]. Wavelet transform is defined as

$$WT(a, b) = \frac{1}{\sqrt{a}} \int s(t)\psi(\frac{t-b}{a})dt, a \in R, b \in R$$

where a stands for scale parameter and b stands for translation parameter. In wavelet transform, the larger the value of a , the wider the primary function of time domain and the narrower the frequency domain; the smaller the value of a , the narrower the primary function of time domain and the wider the frequency domain. Moreover the product of a and b is

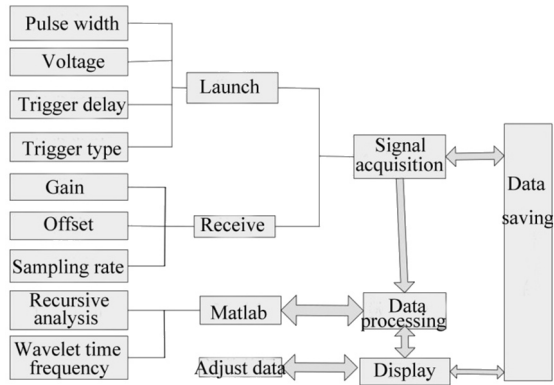


Fig. 1. The software architecture

a fixed value. It means that wavelet transform has low time resolution and high frequency resolution at low frequency end of signals and low frequency resolution and high time resolution at high frequency end of signals.

The application of time-frequency analysis in ultrasonic non-destructive detection is usually based on ultrasonic frequency attenuation model [13], i.e. identifying the defects of materials through observing the variation characteristics of signal frequency.

2. Experimental

2.1. Establishment of ultrasonic non-destructive detection system platform

Firstly the software framework was developed based on Lab View [14] and MATLAB platform. According to functions and use, system software could be divided to four parts, i.e. data acquisition, signal processing, data storage and data display (Figure 1).

Data acquisition. Data acquisition based on personal computer was realized by obtaining reflective ultrasonic data from materials using an ultrasonic probe.

Signal processing Ultrasonic echo-signals were processed with smoothing and wavelet time frequency methods using MATLAB in combination with Lab View.

Analysis and processing of ultrasonic signals

The analysis and processing of ultrasonic echo signals was an important step in the identification and quantification of defects in non-destructive detection. Time-frequency analysis is the main analysis and processing means.

Test. This test was carried out to verify the reliability of ultrasonic non-destructive detection software system and obtain the ultrasonic echo signal of real carbon fibre composite.

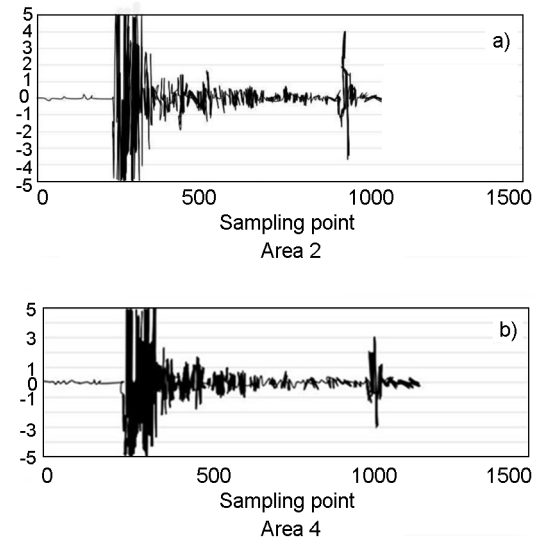


Fig. 2. The ultrasonic detection signals of the test material

The main test content includes dividing signal acquisition into eight small areas and detecting them to obtain ultrasonic signals of different areas, doing repeated test to repeatedly sampling in the acquisition areas and analyze data coincidence degree, and processing and calculating the obtained data and evaluating the possible defects inside the material according to the analysis results.

The test material was carbon fibre composite test specimen provided by an aircraft manufacturing company in China. The test specimen was mainly composed of 72 fibre layers and a resin layer. The average thickness of the fibre layers was 0.125 mm, and the thickness of the resin layer was 0.01 mm.

The ultrasonic detection software mentioned in the last chapter was used for the analysis and processing of test data. The detection system mainly included water channel, clamping and holding device, data connecting wires, transduction auxiliary coupling support, ultrasonic transducer, ultrasonic data acquisition card and computer.

Water-logging ultrasonic pulse pulse-echo method was used. The ultrasonic transducer was installed on the auxiliary coupling support. After air was expelled, the distance between the probe and the surface of the test specimen was adjusted; then the marked areas were measured one by one. The carbon fibre composite with thick cross section had large bottom echo signal attenuation. To obtain effective test data, an immersion ultrasonic probe with center frequency of 7.5 MHz was used. The sampling frequency was set as 100 MHz.

Area 2 and 4 were selected as the observation objects (Figure 2).

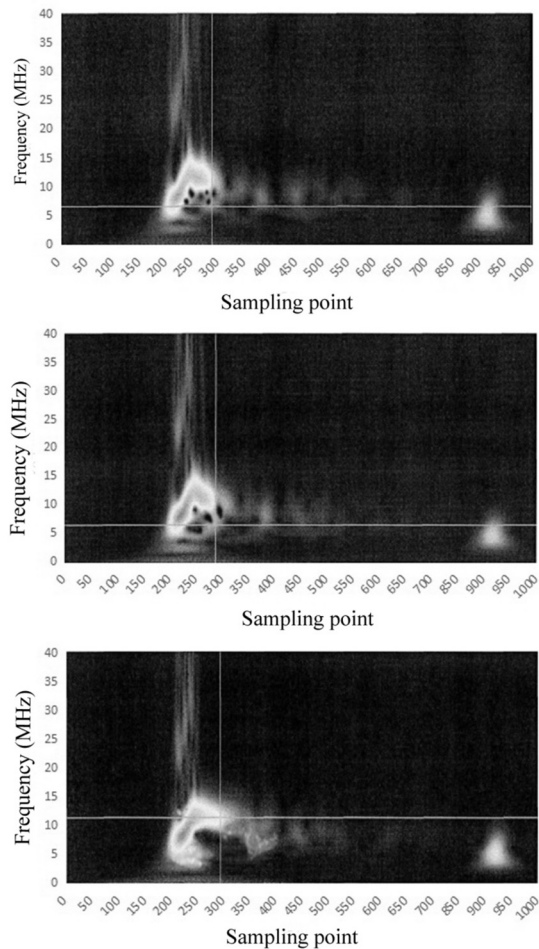


Fig. 3. The time-frequency analysis results of signals in area 2 (a), 4 (b) and normal area (c).

There were a large number of resonance signals around the front surface of the detection signals in area 2 and 4. The bottom echo signals were long and had clear characteristics. Backscattered signals between front surface echo signals and bottom echo signals had large amplitude and obvious attenuation trend. The energy of the backscattered signals suggested local increase and decrease, and its characteristics were relatively complex. The local amplitude of detection signals in some areas had mutation, which might be caused by internal defects of the material.

3. Results and discussion

Time-frequency analysis function of the software was used to process the sampling signals to obtain the time-frequency analysis results of the detection signals. The defects of the material could be determined through observing the variation tendency of frequency in the time-frequency figure (Figure 3).

Figure 3(a) and (b) demonstrate the time-frequency analysis results of the detection signals in area 2 and 4. It was observed that signal concentration and frequency declined. Figure 3(c) suggests the time-frequency analysis results of the detection signals in a normal area; the decrease of frequency component was relatively smooth. But there was an obvious difference between (a) and (b). It could be determined that area 2 and 4 had defects according to the time-frequency analysis results, which was consistent with the results of recurrence quantification analysis.

4. Conclusion

In this study, the defects of carbon fibre composite were analyzed using ultrasonic non-destructive detection system and ultrasonic non-destructive detection and signal processing methods. Ultrasonic non-destructive detection software was used to detect the divided areas and confirm the areas with defects. This work verified the feasibility of the detection system and the effectiveness of time-frequency analysis method in the analysis and identification of defects of carbon fibre composite.

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