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The Application of Helicopter Rotor Defect Detection Using Wavelet Analysis and Neural Network Technique

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Abstract: When detect the helicopter rotor beam with ultrasonic testing, it is difficult to realize the noise removing and quantitative testing. This paper used the wavelet analysis technique to remove the noise among the ultrasonic detection signal and highlight the signal feature of defect, then drew the curve of defect size and signal amplitude. Based on the relationship of defect size and signal amplitude, a BP neural network was built up and the corresponding estimated value of the simulate defect was obtained by repeating training. It was confirmed that the wavelet analysis and neural network technique met the requirements of practical testing. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Ultrasonic testing, Wavelet analysis, Artificial neural network, Helicopter rotor defect.

1. Introduction

Ultrasonic testing is widely used in the detection of aviation components as its advantages of strong penetrability, high sensitivity, good ability of locating and quantifying the defects and facility. As the echo signals contain the defect signals and noise signals at the same time, and the weak defect signals are easily drowned by the noise, therefore the method of identifying the defect signal from the noise is needed [1-3]. The wavelet analysis which is excellent in the signal process field is used to change the flaw echo of helicopter rotor beam from time domain to frequency domain [4]. The useful information of amplitude and frequency are utilized to extract the defect characteristic parameters. Then the parameters are used to quantitative evaluate the defects through artificial neural networks. The results show that the demand of the quantitative testing of the defect of helicopter rotor beam can be met by this method.

2. Flaw Sample Preparation

The principle of ultrasonic testing indicates that the instrument could identify the defect signals only if the ultrasound probe received the reflecting acoustic pressure and converted them into the electrical signals.

The amplitude of reflecting acoustic pressure is proportionate to the area of defect which is perpendicular to the direction ultrasound travels. According to the national military standard GJB593.1-88 NDT Quality Control Specification in the testing of ultrasonic longitudinal wave and transverse wave, the middle part of helicopter rotor beam in service was used as the sample. Ten artificial defects were made on the sample with the depth of 1mm, the width of 0.1 mm and their lengths were 2 mm, 4 mm, 6 mm, 8 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm and 20 mm. The picture of defective sample is shown in Fig. 1.

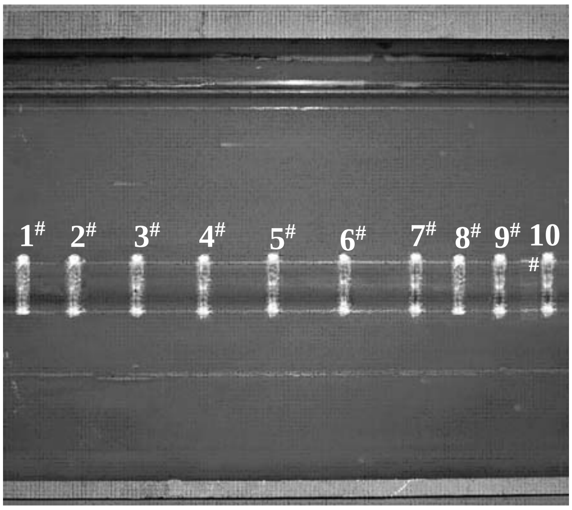


Fig. 1. The defective sample in middle part of helicopter rotor beam.

3. Signal Acquisition

The type of ultrasonic instrument used was MUT-1. The size of crystal shear wave probe was 10 mm×10 mm, its angle of incidence was 53° and the center frequency was 2.5 MHz. The original signals collected are shown in Fig. 2. The signal in Fig. 2(0#) represents the sample without defects, and Fig. 2(1#)~Fig. 2(10#) are the condition of the defect signal with the defect lengths of 2 mm, 4 mm, 6 mm, 8 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm and 20 mm.

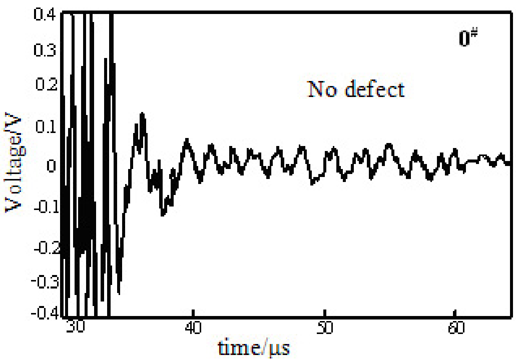


Fig. 2 (0#). The original signals of samples.

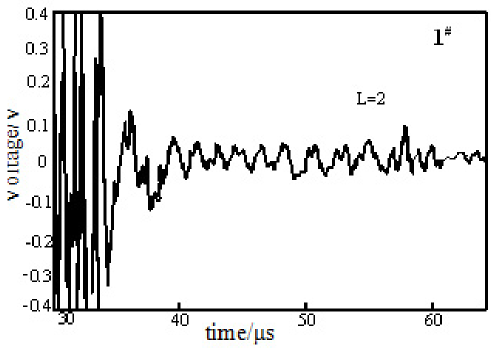


Fig. 2 (1#). The original signals of samples.

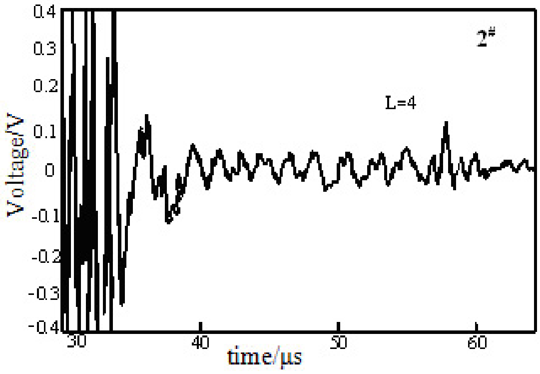


Fig. 2 (2#). The original signals of samples.

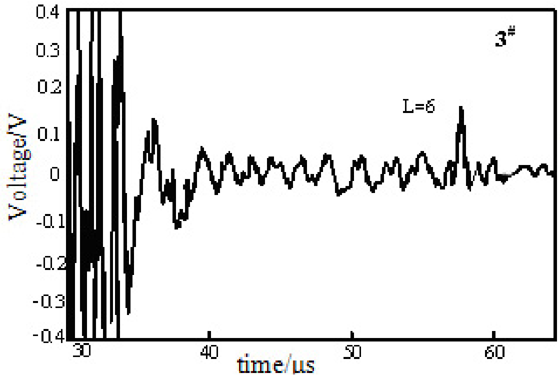


Fig. 2 (3#). The original signals of samples.

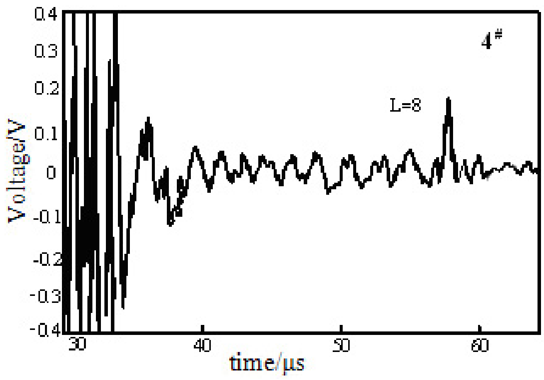


Fig. 2 (4#). The original signals of samples.

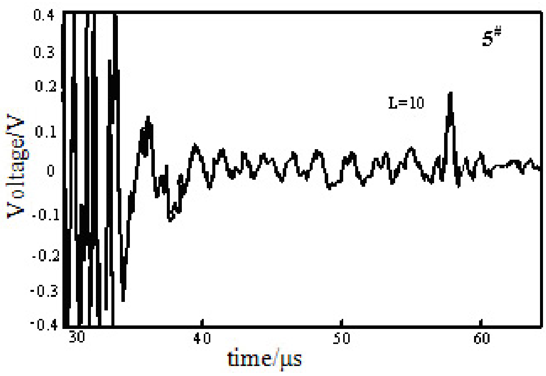


Fig. 2 (5#). The original signals of samples.

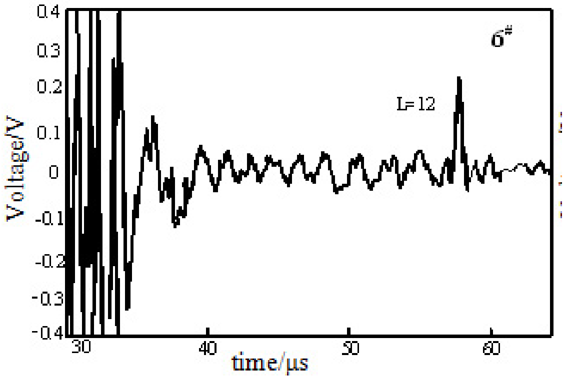


Fig. 2 (6#). The original signals of samples.

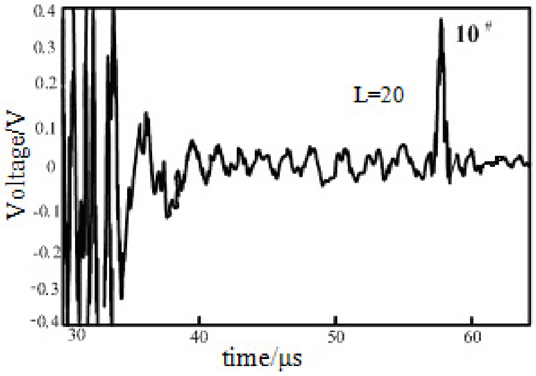


Fig. 2 (10#). The original signals of samples.

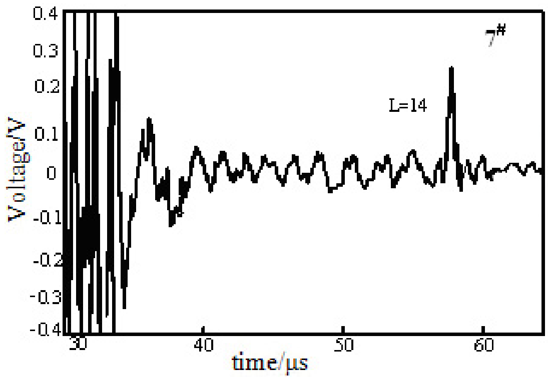


Fig. 2 (7#). The original signals of samples.

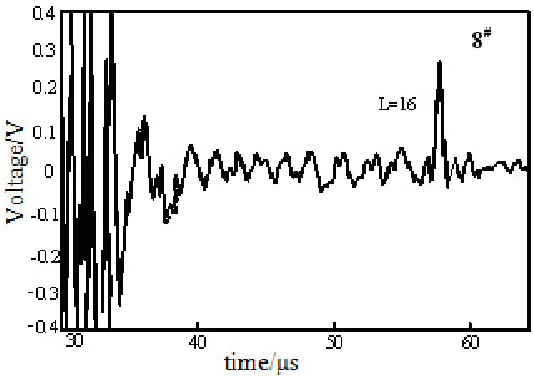


Fig. 2 (8#). The original signals of samples.

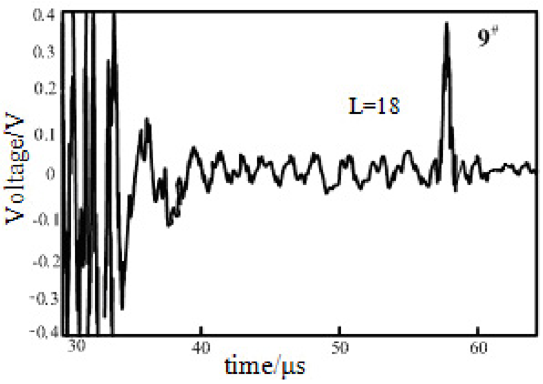


Fig. 2 (9#). The original signals of samples.

4. Signal Noise Processing with Wavelet Analysis Technology

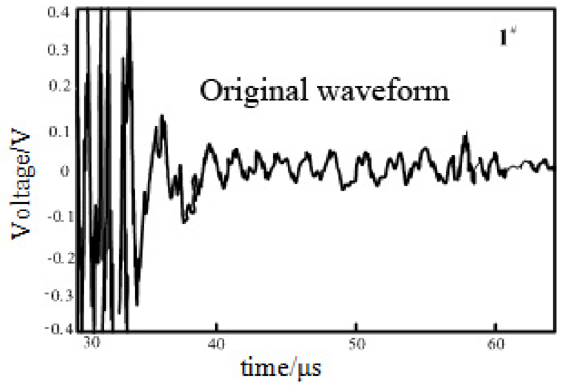
The defect signals are inevitably interfered or even drowned by the noise signal in the ultrasonic testing. It is difficult to identify the defect signals from the interfered signals directly and the result is not accurate enough. In actual terms, processing the collected signals with wavelet analysis technology can always make the result more accurate and this method helps to determine the structural defects accurately [3, 4].

The key point of using wavelet de-noising method is the quantization of wavelet coefficients, i.e. part of wavelet coefficients are reset by using the selected threshold. The soft-threshold is used in this paper, that is to say the absolute value of wavelet coefficients are compared with the threshold, the wavelet coefficients become to zero when the coefficients are less than or equal to the threshold, and the wavelet coefficients become to their difference when the coefficients are greater than the threshold. In the experiment, the 2 mm length artificial defect was detected, the obtained ultrasonic echo were imported into the wavelet analysis tool in Mat lab, chose the wavelet function of danbeclues to conduct the multi-scale analysis and wavelet compression, then the corresponding original waveform and the de-noised waveform were obtained. The result is shown in Fig. 3. Fig. 3(a) is the original waveform, Fig. 3(b) is the de-noised waveform. As is shown in Fig. 3, part of the defect waveform changes from the unrecognized envelop to the obvious characteristic peak by this method, the recognition of the defect signal is improved.

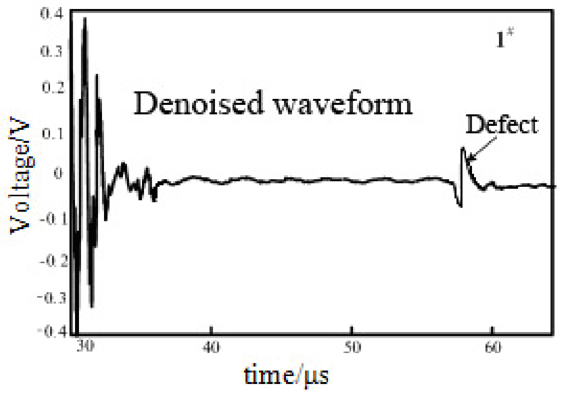
5. Evaluation the Defect with Artificial Neural Network Technology [5, 6]

5.1. The Relationship between Defect Amplitude and Defect Dimension

By analyzing the defect signal, the relationship between defect voltage amplitude and defect dimension is shown in Fig. 4. Defect dimension has the correspondence with defect amplitude under a given frequency. As the increase of defect length, the voltage of sensor output is increased, but it is a non-linear relationship.



(a)



(b)

Fig. 3. The comparison of ultrasonic testing signal.

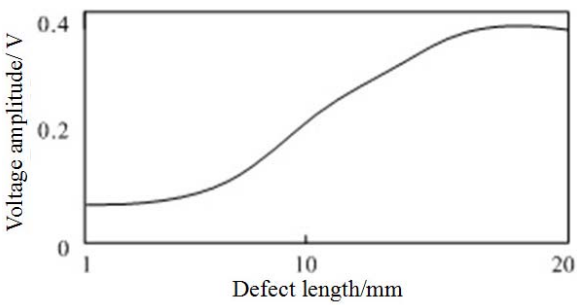


Fig. 4. The characteristic curve of defect.

5.2. The Evaluation of Defect Dimension

The constructed BP neural network is shown in Fig. 5. It consists of three layers, the input layer, the hidden layer and the output layer. The number of neurons in the hidden layer is ten. Set two input values which are defect length and voltage amplitude, and two output values which reflect the information of defect dimension. The network has the output of supervised learning, its setting is shown in Table 1.

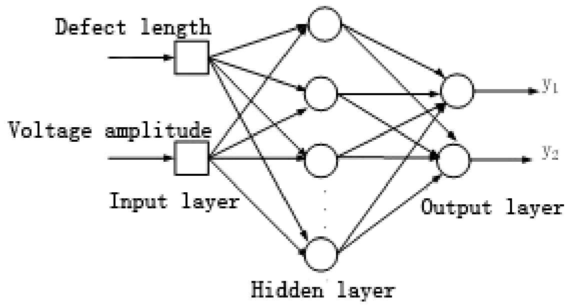


Fig. 5. The structure of BP network.

Table 1. The output settings of artificial neural network.

Output	Setting	Defect Length [mm]
(y_1, y_2)	(0.1, 0.9)	2
(y_1, y_2)	(0.2, 0.8)	4
(y_1, y_2)	(0.3, 0.7)	6
(y_1, y_2)	(0.4, 0.6)	8
(y_1, y_2)	(0.5, 0.5)	10
(y1, y2)	(0.6, 0.4)	12
(y1, y2)	(0.7, 0.3)	14
(y1, y2)	(0.8, 0.2)	16
(y1, y2)	(0.9, 0.1)	18
(y1, y2)	(1.0, 0.0)	20

As the number of samples was limited, in order to guarantee the sufficiency and typicalness of samples set, and to account the randomness and independence between training samples and processing samples at the same time, the paper adopts measures as follows: firstly, training the network with the results of measurements which test four times, the instrument setting of the fourth measurement was different from the previous. Secondly, take the alternate circulating network as training method. Use the P of the first three measurements of any eight defect samples to train the neural network, and use this network to deal with the P of the fourth measurement of the last two defect samples, and then give the evaluation of the two defects. Repeat the process until all the defect samples are evaluated. The processed results are shown in Table 2.

The obtained regulation of evaluation to the defect dimension can be calculated with equation 1:

$$L = y_1 \times 20\,(mm) \tag{1}$$

According to Table 1 and Equation 1, the evaluations of defects dimension are obtained which are shown in Table 2. The evaluations of the defects are close to nominal value, and the comparison results are shown in Fig. 6. In this figure, a small circle corresponds to an evaluation. The points on 45-degree slanting line represent the evaluations equal to the nominal values.

Table 2. The processing results of artificial neural network.

Nominal Value [mm]	Output		Evaluation of defect [mm]
	y1	y2	
2	0.108	0.892	2.16
4	0.219	0.781	4.38
6	0.292	0.708	5.87
8	0.396	0.604	7.92
10	0.494	0.506	9.88
12	0.614	0.386	12.27
14	0.718	0.282	14.36
16	0.793	0.207	15.86
18	0.929	0.072	18.57
20	0.966	0.034	19.32

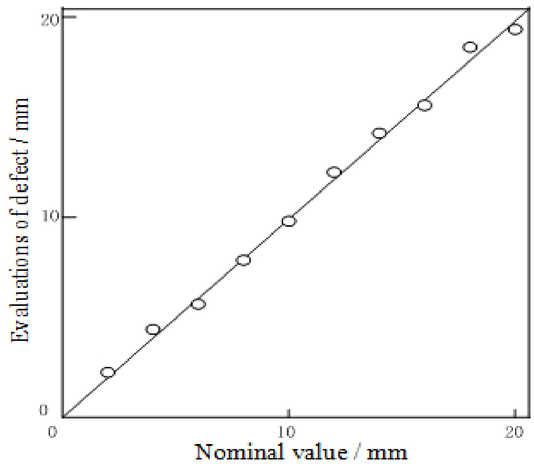


Fig. 6. The evaluations of defect dimension.

5.3. Error Analysis

The relative error of measurement R_1 is calculated with equation 2:

$$R_1 = \frac{\sum_1^3 |P - P_m|}{3P_m} \quad (2)$$

P is the P_1, P_2 or P_3 of one sample, Pm is the average value of measurements which test three times. R_1 represents the discrete level of the measured data. By analyzing original data, the relative errors of most samples are within 10 %. It is necessary to have a range of proper error for the data which is used to train the network. It makes the network have the ability of fault tolerance. And the values of defects to be measured also have the error.

The relative error of defects estimate R_2 is calculated with equation 3:

$$\boldsymbol{R_2} = \frac{\boldsymbol{l_g} - \boldsymbol{l_b}}{\boldsymbol{l_b}} \quad (3)$$

where l_g is the estimate value of one sample, l_b is its nominal value.

The relative error analysis of defects estimate with neural network is shown in Fig. 7. The relative errors of defect samples are all within 10 %. This result is acceptable.

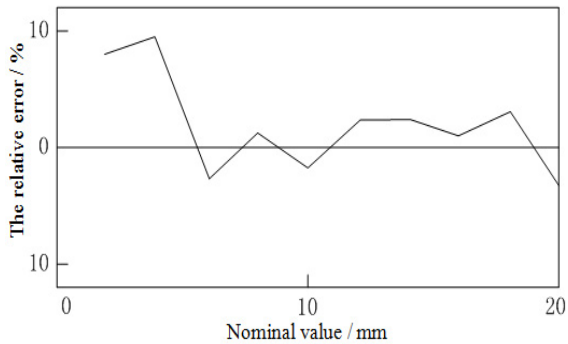


Fig. 7. The relative error of defects estimate.

6. Conclusion

The wavelet analysis technology and artificial neural network were used to de-noise the signal got from the defects on helicopter rotor beam and give the quantitative evaluation in this paper. The satisfactory de-noising result was achieved by importing the ultrasonic echo into the wavelet analysis tool in Mat lab and choosing the wavelet function of danbeclues to conduct the multi-scale analysis and wavelet compression. The characteristic curve of defect amplitude and defect dimension was acquired. As the curve shows, the defect dimension only relates to the amplitude under the given frequency. Setting the output of neural network, the evaluation of defect dimension was obtained by repeated training. The experimental results showed that the error of quantitative evaluation of defects was within 10 %, which met the requirements in practical testing.

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