Signal Analysis of Ultrasonic C-Scan Testing for Multi-layer welding Structure

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Abstract：

The multi-layer welding structure is a kind of important weld component used in modern aviation industry. In order to control the quality of the inner welds, the method of ultrasonic immersion testing with focusing probe has been performed in this study. Some testing signals displayed in the screen are overlapping signals composed by the echoes with different propagation routes in the multi-layer welding structure. In this paper, a method is given to recognize the valid signal basing on the analysis of sound routes. Computer simulation and a series of experiments are performed to prove the validity of the method.

Key words：multi-layer welding structure, ultrasonic testing, overlapping signal ,computer simulation

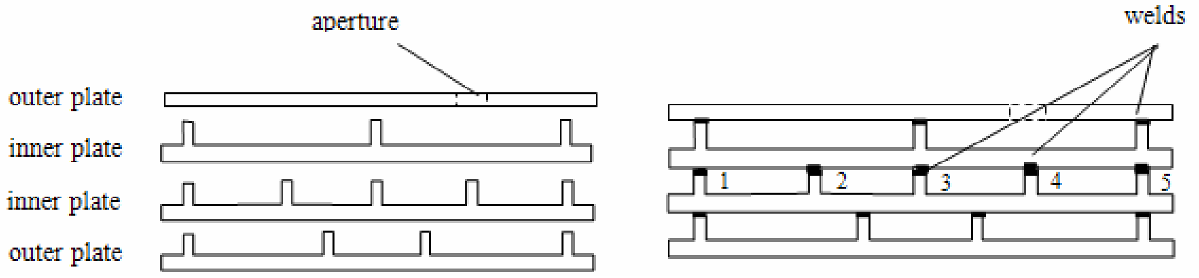
1. Introduction

As a kind of important weld component, the multi-layer welding structure consists of several sheets of metal plates which are brazed together with empty space between each other. This kind of welding structure has been paid a great attention in modern aviation industry because of its light weight, high capability, low cost and so on. However, effective NDT method for controlling the quality of this kind of welds is absent due to its complicated structure. A research about the ultrasonic testing method for the multi-layer welding structure has been conducted in this paper.

The method of ultrasonic immersion testing with focusing probe is performed on account of the empty space in the multi-layer structure. The ultrasonic beams can get to the inner welds passing the water filling in the empty space. Some of the test signals displayed in the screen are overlapping signals composed by the echoes with the different propagation routes in the multi-layer welding structure. The sound waves reflected by the inner welds are named effective echoes. And the sound waves reflected by the other parts in the multi-layer welding structure are named interferential echoes. The emphasis of this study is to recognize the optimal echoes for C-scan in which the energy of the effective echoes is higher than the energy of the interferential echoes.

2. The Propagation Routes of Acoustic Beam in the Multi-layer Welding Structure

In order to simulate the multi-layer welding structure, a specimen is designed as shown in fig 1. Four sheets of aluminum alloy plates with the same thickness are welded together and there is empty space between the arbitrary two contiguous aluminum alloy plates.



a. before welding b. after welding

Fig 1. The configuration of multi-layer weld apecimen

The welds between the outer plate and the inner plate are easy to test using the ultrasonic C-scan method directly. But the welds between the two inner plates are difficult to test because of the phenomena of the superposition of acoustic beams reflected by the different plates.

As shown in fig 2, there are two kinds of inner welds with the different positions, one labeled 1、3、5 and the other labeled 2、4. To test the welds of one kind , the route of ultrasonic transmitting from the probe to the inner welds is water aluminum alloy top weld aluminum alloy mid weld. When there is no defect in the top weld, the acoustic route of ultrasonic can be simplified to water aluminum alloy mid weld. So the mid welds can be tested using ultrasonic C-scan method. Fig 3 shows the A-scan and C-scan images for it. In the case, the A-scan waveform is simple to identification and the C-scan image is clear to see the defect.

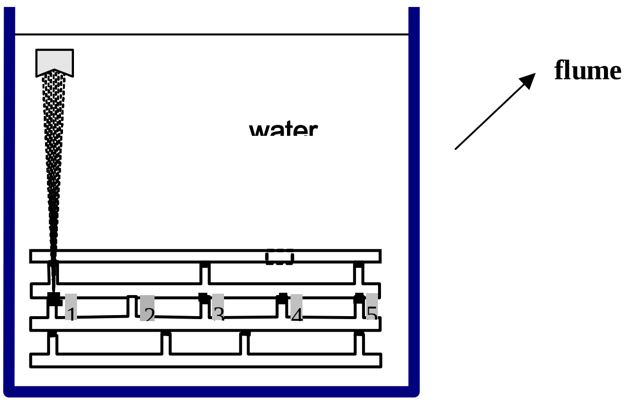
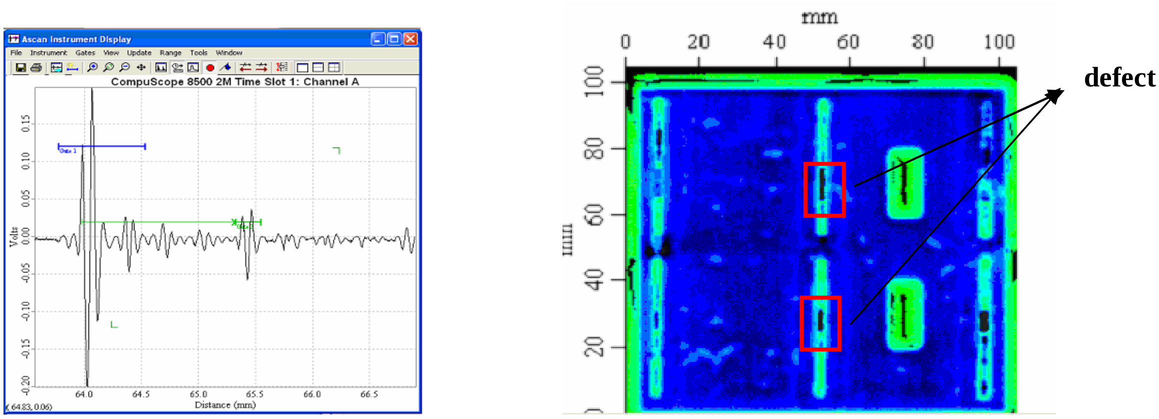


Fig 2 .The sketch map for test

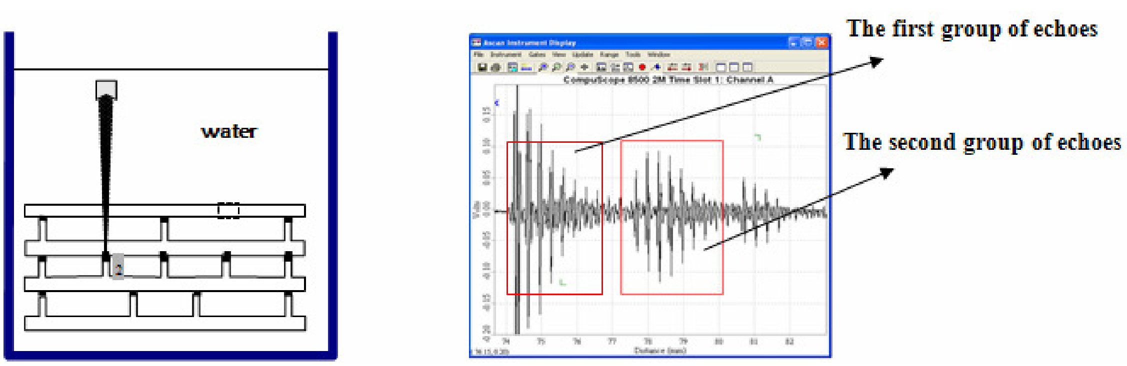


a. practical A-scan image b. practical C scan image

Fig 3 . The instance for testing the weld of the first kind of position

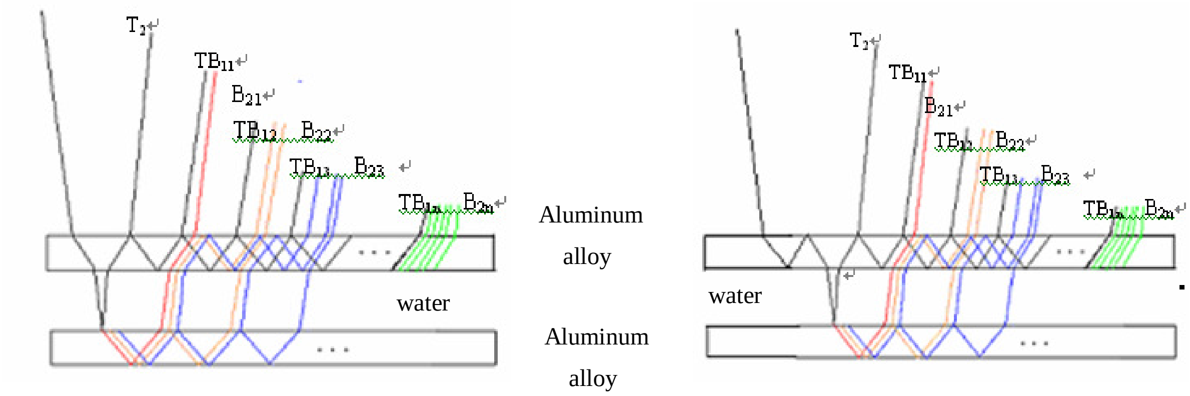
To test the welds of the second kind, the route of ultrasonic transmitting from the probe to the weld is water aluminum alloy water aluminum alloy mid weld. Fig 4 shows the instance for it. In the A-scan waveform for the test, the first group of echoes is reflected by outer plate directly at different times, and the second group of echoes is reflected by the outer plate and the inner plate, which includes the information of inner weld. It is difficult to distinguish the echo reflected by the inner weld because of the interposition of water between the two plates.

In order to know how the echoes superposed, Fig 5 shows the detailed routes of ultrasonic transmitting in the specimen. In fig 5, T_2 denotes the wave reflected by the surface of the second-layer plate and TB_{1n} denote the waves reflected by the bottom of the first-layer plate for different times. These two kinds of echoes do not arrive at the mid weld and don't contain the information of defect in it. So they are disturbing echoes. B_{2n} denote the waves reflected by the bottom of the second-layer plate. This kind of echoes contains the information of defect in the mid weld and is effective echo. The beams in figure 5-b are all reflected by the bottom of the first plate once first, and then diffuse Rin the same route with the beams in fig 5-a. So there is a time delay from the beams in fig 5-a to he beams in fig 5-b. The echoes with the same transmission time compound together and form the one echo in the screen, such as shown in fig 4-b.



a. The sketch map for test b. practical A-scan image

Fig 4 . The instance for testing the weld of the first kind of position



a. The superposition of ultrasonic arriving at the second plate directly

b. The superposition of ultrasonic wave arriving at the second plate after reflected by the first plate

Fig 5 . The routes for ultrasonic superposition

In order to investigate the rule of the sound wave superposition, a kind of array is given below. The superscripts in the array (n) denote the times of the sound wave reflected in the plates.

$T_2^{(1)}$	$TB_{11}^{(1)}$	$TB_{12}^{(1)}$	$TB_{13}^{(1)}$	$TB_{14}^{(1)}$	$TB_{15}^{(1)}$	$TB_{16}^{(1)}$	
	$B_{21}^{(1)}$	$B_{22}^{(1)}$	$B_{23}^{(1)}$	$B_{24}^{(1)}$	$B_{25}^{(1)}$	$B_{26}^{(1)}$	
	$T_2^{(2)}$	$TB_{11}^{(2)}$	$TB_{12}^{(2)}$	$TB_{13}^{(2)}$	$TB_{14}^{(2)}$	$TB_{15}^{(2)}$	
		$B_{21}^{(2)}$	$B_{22}^{(2)}$	$B_{23}^{(2)}$	$B_{24}^{(2)}$	$B_{25}^{(2)}$	
		$T_2^{(3)}$	$TB_{11}^{(3)}$	$TB_{12}^{(3)}$	$TB_{13}^{(3)}$	$TB_{14}^{(3)}$	
			$B_{21}^{(3)}$	$B_{22}^{(3)}$	$B_{23}^{(3)}$	$B_{24}^{(3)}$	…… (1)
			$T_2^{(4)}$	$TB_{11}^{(4)}$	$TB_{12}^{(4)}$	$TB_{13}^{(4)}$	
				$B_{21}^{(4)}$	$B_{22}^{(4)}$	$B_{23}^{(4)}$	
				$T_2^{(5)}$	$TB_{11}^{(5)}$	$TB_{12}^{(5)}$	
					$B_{21}^{(5)}$	$B_{22}^{(5)}$	
					$T_2^{(6)}$	$TB_{11}^{(6)}$	
						$B_{21}^{(6)}$	
						$T_2^{(7)}$	

A line of the data in the vertical direction in the array (1) will overlap together in the test. The proportion of the energy of the disturbing echoes and the effective echoes is given by the formula (2)-(6). Using a focused probe, there is an angle between the incidence sound and the surface of the specimen. The angle is small enough to be neglected here. It is supposed that the sound transmit into the specimen vertically. The attenuation and diffusion of the sound wave diffusing in the specimen are ignored, too.

$$P_i = K_i P_O \qquad (2)$$

$$K_i = K_1 T_2^{(i+1)} + \sum_{j=1}^{i} K_2 TB_{1j}^{(i+1-j)} + \sum_{j=1}^{i} K_3 B_{2j}^{(i+1-j)} \qquad (i = 0,1,2,3\Lambda) \tag{3}$$

$$K_1 T_2^{(i+1)} = t_1^2 t_2^2 r_1 \left(r_2^2\right)^i \tag{4}$$

$$K_2 TB_{1j}^{(i+1-j)} = t_1^2 t_2^2 r_1 \left(r_2^2\right)^i \tag{5}$$

$$K_3 B_{2j}^{(i+1-j)} = j t_1^3 t_2^3 r_2 \left(r_2^2\right)^{i-1} \tag{6}$$

P_0 __ the pressure of the incident wave

P_i __ the pressure of the reflected wave

K_i __the proportion coefficient

r_1__ ratio of the reflection at the interface from water to aluminum alloy

r_2__ ratio of the reflection at the interface from aluminum alloy to water

t_1__ ratio of the transmission at the interface from water to aluminum alloy

t_2__ ratio of the transmission at the interface from aluminum alloy to water

3. Computer simulation and the analysis of the example

3.1 Computer simulation

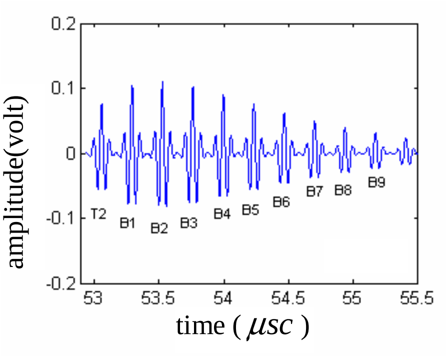
The value of r_1、r_2、t_1 and t_2 in the formula (4)-(6) are 0.842、-0.842、1.842 and 0.152 respectively. Basing on the four numbers above and the formula (2)-(6), a series of the proportion coefficients of the echo pressure can be counted. Table 1 gives the pressure coefficients of disturbing echoes and effective echoes and the pressure ratio of effective echo to disturbing echo. B_1 in table (1) denotes the first echo in the second group echoes (as shown in fig 4-b), B_2 denotes the second echo in the second group echoes, and so on.

Table 1 contrast with the pressure coefficients of different echoes reflected by the second plate

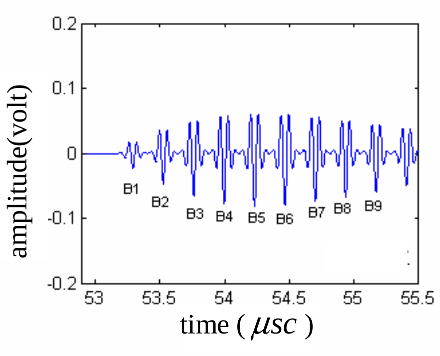
	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9
$T_2^{(i)} + TB_{1n}^{(i)}$	0.0749	0.1050	0.1104	0.1032	0.0904	0.0760	0.0622	0.0498	0.0393
$B_{2n}^{(i)}$	0	-0.0224	-0.0471	-0.0660	-0.0771	-0.0811	-0.0796	-0.0744	-0.0670
$B_{2n}^{(i)}/(T_2^{(i)}+ TB_{1n}^{(i)})$	0	0.2133	0.4267	0.6400	0.8534	1.0667	1.2801	1.4934	1.7067

Gauss function is used to simulate the ultrasonic signal. The waveforms of the second group are simulated by matlab software basing on the number in table (1).

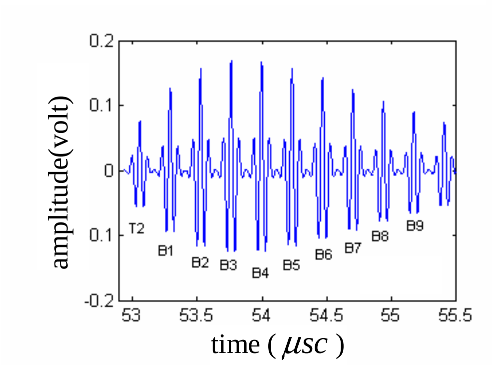
As shown in fig 6, the energy of B_2 is strongest in the disturbing echoes, and the energy of B_4、B_5 and B_6 are all stronger than the other in the effective echoes. The pressure ratio of effective echo to disturbing echo becomes bigger with the reflection times increasing. So in the complex signal, B_4、B_5 and B_6 with the stronger effective echo and weaker disturbing echo are the optimal echoes to be chose for C-scan.



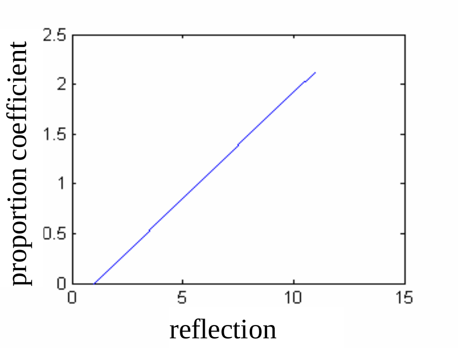
a. The waveform of the disturbing echo



b. The waveform of the effective echo



c. The waveform of the complex signal



d.The ratio of two kinds of echo

Fig 6 . Simulative waveform of testing the inner weld

3.2 The analysis of the example

To validate the validity of the simulation, an experiment of C-scan testing is done with the high frequency and focusing probe[1]. First, adjust the distance between the probe and specimen to make the focus of the probe in the inner weld. Then put the signal gate for C-scan at the echo of B_4、 B_5 or B_6. Fig 7 shows the A-scan waveform in the practical test, which is similar with the simulation A-scan waveform in fig 6-c. In the experiment, the signal gate is put at the echo of B_4 and the result of C-scan is shown in the fig 8. Fig 9 shows the drawing of the specimen. Comparing the fig 8 and fig 9, the defect in the specimen can be present in the C-scan testing image. That is to say that the analysis above is correct.

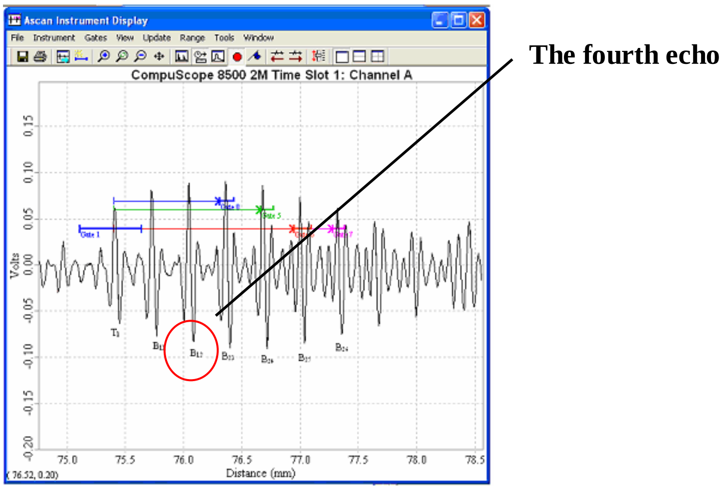


Fig 7 . Practical A-scan waveform of the inner weld test

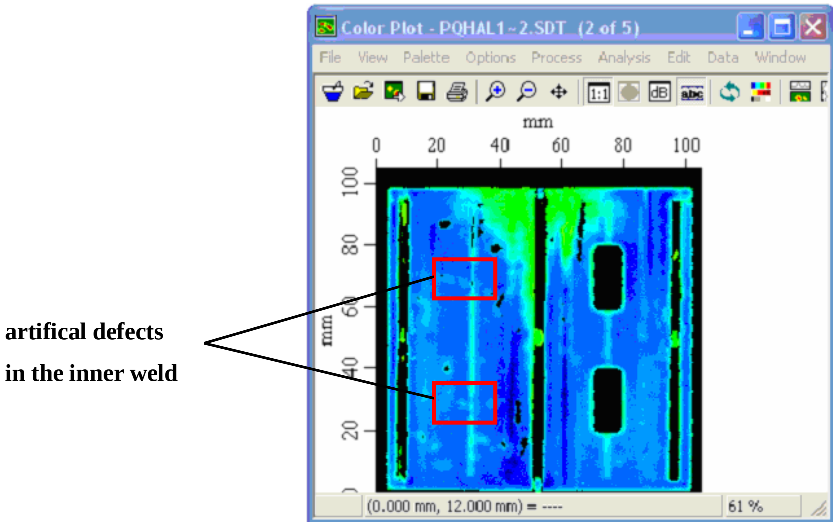


Fig 8 . Practical C-scan image of the inner weld test

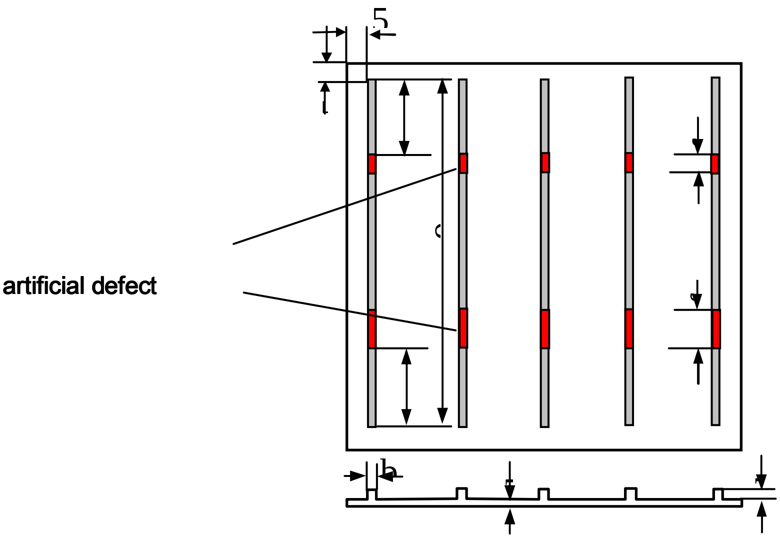


Fig 9 . The drawing of the specimen

4. Conclusion

In this paper, we have proposed the method about how to test the inner welds of the multi-layer welding structure. For the work, we have analyzed the rule of superposition of different echoes, simulated the A-scan waveform to choose the right echo for C-scan, and done the experiment to validate it. At last, two conclusions are made as follows:

1、The inner weld can be test using the method of ultrasonic C-scan testing with high frequency and focusing probe.

2、The right C-scan image can be get by the analysis of sound routes and choice of the right echo for C-scan.

Reference

[1] Yiwei SHI. Ultrasonic Test. Machine Technology Press, 2005.