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Research on Line-scan Inspection Method with Guided Waves

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Abstract

Ultrasonic guided wave can propagate over a long distance and can be used to inspect plate and shell structure. Line-scan method is always applied to guide wave inspection. However, it is a problem how to locate the defects and how to image the inspection results if the through transmission method is used. In order to solve this problem, the imaging method of inspection results with ultrasonic guided waves is studied. The line-scan inspections respectively with pulse echo method and through transmission method are introduced. The X-Y dimension cross product and adding method is finally emphasized on. Defect's location and size are solved and the inspection result is imaged when aluminum skin honeycomb core sandwich structure specimen is inspected. The experiment results show that the X-Y dimension cross product and adding method can solve efficiently the problem of defect location and size when through transmission method is used in guided waves line-scan inspection.

Keywords: Honeycomb core sandwich structure, Guided waves, X-Y dimension cross product and adding method

Ultrasonic guided waves inspection technology are developed quickly recently. Compared with traditional ultrasonic waves, guided waves can propagate over a long distance in wave guides. The received signal includes the information between the excitation point and receiving point. Line scan can just be used to inspect the structure not the scanning point by point, which is time-consuming and cost-lost for the large structures inspection. Now the guided waves have been applied to the inspection of plate and shell as well as pipes etc.

Xu Kebei researched the inspection method of plate with guided waves, and analyzed the results respectively from the energy and displacement [1]. Marical P. studied the guided waves traveling in the plate whose cross sections were variable [2].Toyama N. made a research on quantitative damage detection in cross-ply laminates using Lamb wave method[3].Quarry M. J. analyzed the guided waves on laminated plates[4]. Hay T. R. inspected the de-bond defect in skin honeycomb core sandwich structure[5]. He Cunfu used guided waves to inspect the defects in pipes and bolts [6-9]. Zhang Haiyan developed the ultrasonic Lamb wave tomography for through hole flaws combing ray tracing with algebraic reconstruction [10].

However, there are few papers about the line scan image technology of guided waves. There are two problems in imaging the guided waves inspection results. Firstly, when through transmission method is used in guided waves inspection, it is difficult to locate the defect position. Secondly, the inspection result image can not be finished only basing on the single scan result. All these bring inconvenience for application of guided waves. In order to solve these problems, X-Y dimension cross product and adding method is promoted in this paper, which can locate the flaw position and visualize the inspection result of guided waves.

1. Line scan of guided waves

The inspection methods of guided wave have pulse echo one and through transmission one. With different method, the defect position can not be located in the same ways.

When the pulse echo method is used, the traveling path of guided wave sees in Figure 1. After the guided waves are excited from transducer in the right edge of plate, they propagate along the plate towards the left of plate. Until they encounter defects or the plate edge, the waves will reflected from the defects or the plate edge. According to the flight time of the waves, the defect position can be easily calculated through time delay method.

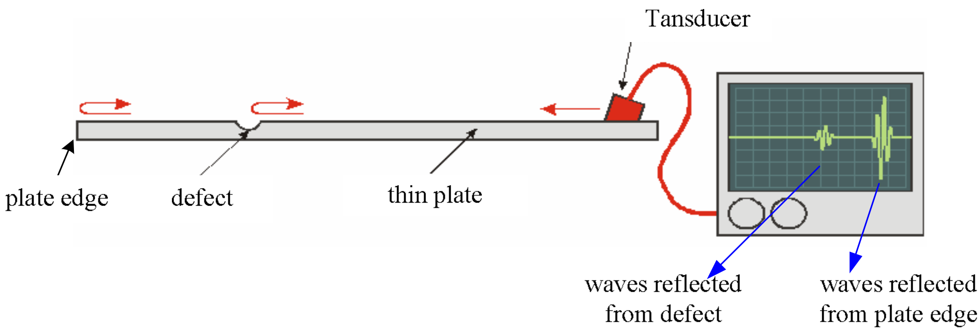

Figure 1 guided waves propagating in the thin plate

While through transmission method is chosen, guided waves (for example in the skin honeycomb core sandwich structure) will propagate in the way showed in Figure 2. Guided waves are excited by the probe in the left and received by the one in the right. Whether the defect exists or not can be judged from the amplitude of received signal. But the specific position of defect is difficult to be decided. For example the signal in Figure 3, we can conclude that there are flaws in term of the amplitude (the threshold amplitude voltage is 20mV.).But the defect may be in any possible positions between the excitation point and the receiving point, just as described in Figure 4. Then how to locate the defect in such cases? And how to image the line scanning inspect result of guide waves? X-Y two dimensions cross product and adding method would overcome these problems in the following.

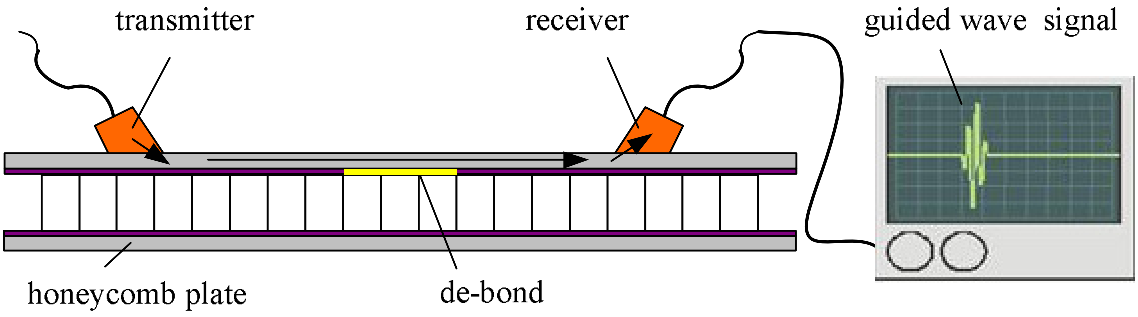

Figure 2 guided waves propagating in honeycomb core plate

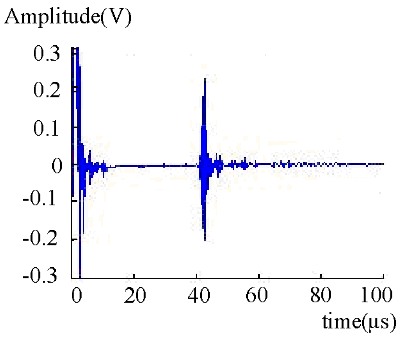

Figure 3 guided waves signal received from receiver with through transmission method

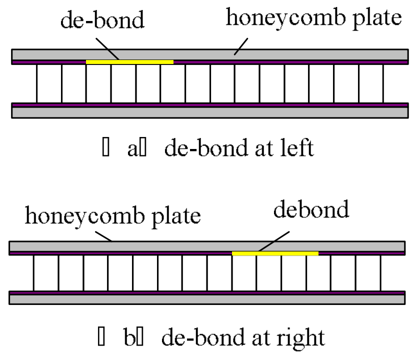

Figure 4 defects in different position

2. X-Y two dimensions cross product and adding method

Some parameters, such as mode, frequency, distance and step value, should be decided before the testing begins when guided waves line scan are applied to inspect structures. Dependent on these data, the structure needs to be scanned in X-Y two dimensions in using X-Y two dimensions cross product and adding method here. Then the two groups of data will be product crossly by unit matrix and add together, at last program them and acquire the image of defects.

The specimen's top view is shown in figure 5(a). P1 and P2 are transducers. Line x2-2 is one of scan lines. Suppose there are two flaws in the line x2-2. The steps of X-Y two dimensions cross product and adding method are as follows.

1) X scan: Based on the scan step value, the transmitter and receiver move synchronously along a line parallel to X axis. Suppose the data number is m, then the record set is written down as column vector X_m, X_m is as following.

$$X_m = [x_1 \quad x_2 \quad x_3 \quad \Lambda \quad x_m]' \tag{1}$$

2) Y scan: Just like X scan, the transmitter and receiver move synchronously along a line parallel to Y axis. Suppose the data number is n, then the record set is written down as row vector Y_n, Y_n is as following.

$$Y_n = [y_1 \quad y_2 \quad y_3 \quad \Lambda \quad y_n]' \tag{2}$$

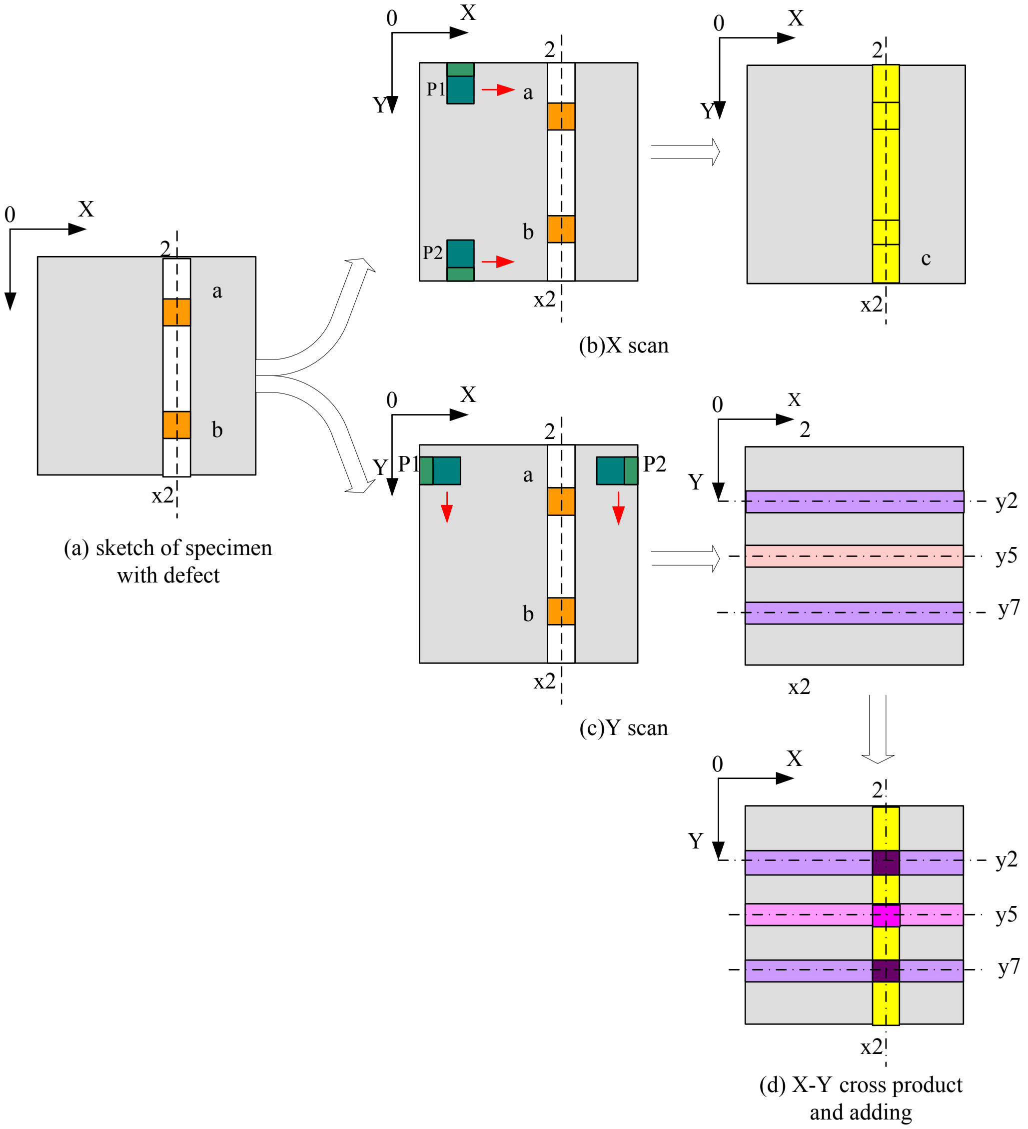

Figure 5 sketch of X-Y two dimensions cross product and adding method

3) Cross product: X_m and Y_n multiply respectively with unit row vector I_n and unit column vector I_m, their cross product are two m×n matrixes named as AX and AY.

$$I_n = [1 \quad 1 \quad 1 \quad \Lambda \quad 1] \text{ , } I_m = [1 \quad 1 \quad 1 \quad \Lambda \quad 1] \tag{3}$$

$$AX = X_m \times I_n = \begin{bmatrix} x_1 & x_1 & x_1 & \Lambda & x_1 \\ x_2 & x_2 & x_2 & \Lambda & x_2 \\ x_3 & x_3 & x_3 & \Lambda & x_3 \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ x_m & x_m & x_m & x_m & x_m \end{bmatrix}_{m\times n}, AY = Y_n \times I_m = \begin{bmatrix} y_1 & y_1 & y_1 & \Lambda & y_1 \\ y_2 & y_2 & y_2 & \Lambda & y_2 \\ y_3 & y_3 & y_3 & \Lambda & y_3 \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ y_n & y_n & y_n & y_n & y_n \end{bmatrix}_{n\times m} \quad (4)$$

4) Adding: transposes the matrix AY to the matrix AY', then AY' adding to the AX equals the matrix A.

$$A = AX + AY' = \begin{bmatrix} x_1+y_1 & x_1+y_2 & x_1+y_3 & \Lambda & x_1+y_n \\ x_2+y_1 & x_2+y_2 & x_2+y_3 & \Lambda & x_2+y_n \\ x_3+y_1 & x_3+y_2 & x_3+y_3 & \Lambda & x_3+y_n \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \Lambda & \mathrm{M} \\ x_m+y_1 & x_m+y_2 & x_m+y_3 & \Lambda & x_m+y_n \end{bmatrix}_{m\times n} \quad (5)$$

5) programs the elements in the matrix A, acquires the image of line scan inspection result of guided waves.

Studying the above steps, it can be found that vector X_m and Y_n represent the line scan results of single direction in step 1 and step 2 where we can judge if the defect exists, but can not locate it. In step 3, the cross products AX and AY distribute the defect on each whole scan line, while the defect only in local segment in fact. For example the signal x2 in the vector X_m, it is acquired from the x2-2 line, see in figure 5(b), after distributing the defect, defect c is equally on the whole line. In step 4, the two set of data are added together according to corresponding position, just here the data of position where exists defect appears out, see in figure 5(c). Because there are defects at a and b, so the corresponding values y2 and y7 is larger than y at other position. After adding, the positions as well as sizes of defects at a and b then appear out.

3. Experimental setup

An inspection test was performed in a through-transmission setup shown in Figure 6. A Panametrics pulser/receiver OLYMPUS-5800 is used as a pulsing system and two broadband variable angle transducers with central frequency of 1.5MHz respectively as transmitter and receiver. After propagating on the plate the signals are measured by an oscilloscope TDS5034B. The specimen used for this study is a aluminum-skin honeycomb core sandwich plate. The aluminum skin is approximately 0.5mm thick. The specimen is 150mm×150mm. The de-bond area is a circular one in the center.

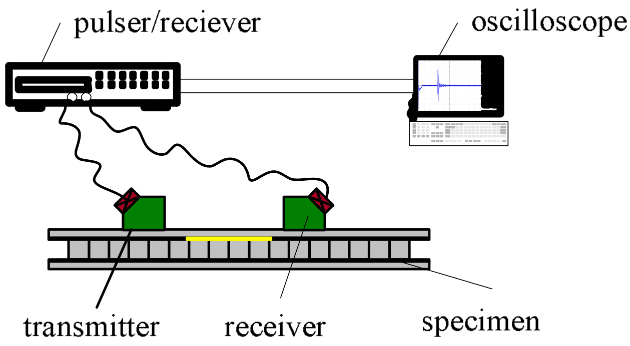

Figure 6 sketch of through transmission experimental setup

4. Result and discussion

4.1 results

Under the condition that the step value is 2mm, the inspection area is 120mm× 120mm around the center. Figure 7 shows the result image.

From the figure 7, it can be known that the defect area is approximately circular one in the center. It locates in the area which is 30.5mm ~ 89.9mm in x direction and 28.3mm ~ 89.5mm in y direction, and the de-bond defect in central area is severer.

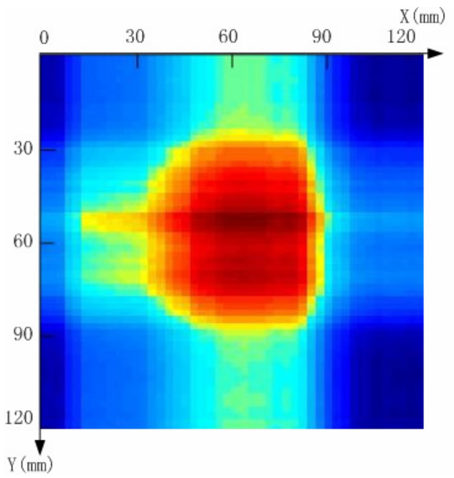

Figure 7 image of honeycomb core plate inspection result with guided wave

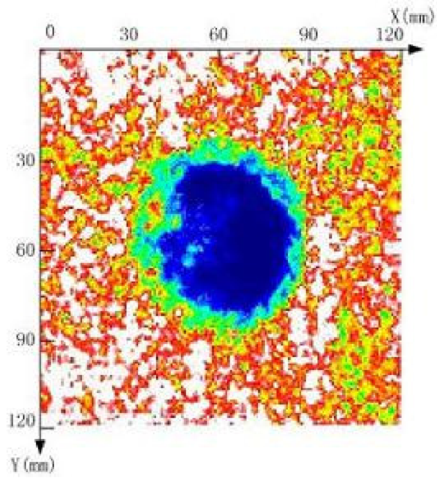

Figure 8 image of honeycomb core plate inspection result with traditional ultrasonic wave method

4.2 Comparison with result of traditional through transmission method

In order to testify the precision of X-Y two dimensions cross product and adding method, the traditional through transmission method is applied to test the same specimen.

Figure 8 shows the result of traditional through transmission method. It can be seen that there is a defect area in the center. The shape of defect is like a circle which is in the area which is 30.5mm～89.1mm in x direction and 29.4mm～89.2mm in y direction. In the central area the defect is severer.

The comparison of examined methods is based on two aspects. The first aspect is related to inspection precision. The second aspect concerns the efficiency in the testing.

On the basis of first aspect, the inspection images are consistent in both defect size and defect position in case of the two methods. As is shown that X-Y two dimensions cross product and adding method can not only locate the defect, but also draw the shape of defect. However, the guided waves method is less than the traditional through transmission method in precision. This could be attributed to the dispersion of guided waves which result that the peak point of wave packet could not be determined precisely. But in some ordinary condition guided waves method can well meet the inspection need. In fact, for those specimens which need to be inspected strictly, many testing methods not only one should be needed to evaluate them .

On the basis of the second aspect, the guided waves method presents much higher efficiency than the traditional ultrasonic method. Suppose the testing area is 120mm×120mm and scan step value is 2mm. With guided waves the probes need to be moved 120 times, but 3600 times in case of traditional ultrasonic wave through transmission method. The efficiency is raised by 30 times. The area is larger, the advantage of guided waves in efficiency is better.

5. Conclusion

(1) When through transmission method is used in guided waves inspection, X-Y two dimensions cross product and adding method is an efficient means to solve the problem of defect location and image. This kind of method is simple and reliable.

(2) Guided waves have more advantage in efficiency over traditional ultrasonic wave method. But the precision of guided waves inspection is less than the traditional through transmission method due to guide waves’ dispersion.

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