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Thin multi-layer plate testing with Ultrasonic Feature Scan Imaging System

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Abstract:

Detection of multi-layer composite material using F-scan ultrasonic imaging system was studied. Layered defects could be identified with focused transducers, and testing results could be displayed by various imaging modes （C、phase feature and CT). Density and thickness of composite material could be measured with the system.

Keywords: F-scan; ultrasonic imaging; multi-layer plate; focused transducer;

1．A characteristic imaging and scanning system

F scan (Feature Scan) is a new technology which has developed since1980s[1].The method was first proposed, and then it used by the Air Force Engineering Center in 1980 and used to detect and evaluate the composite materials[2]. F-Scan includes two features: the first feature is characteristics of ultrasonic waveform: ultrasonic-rise time, fall time, cycle and pulse frequency characteristics; the second feature is characteristics of defects: type, shape and the size. The characteristic of the F-Scan is that the testing results are quantitative, all the records and the information are stored, and the detection results can be identified.

The functions and advantages of F-scan system are the integration of B scan, and C scan, whose detection capacity is exceeding B or C-scan, in addition to the traditional scanning functions, signal spectrum analysis and digital filtering is used in this method; Through the various features of extraction and reconstruction, we can get ultrasound tomography; All the information can automatically be stored in the computer for the detailed analysis and reviewing.

The key of the F-scan technology is research, extraction and identification of the unknown defected characteristics. It needs special transducer to acquire waveform information when measuring, and acquaint the entire signal waveform, then store the information in the computer, process

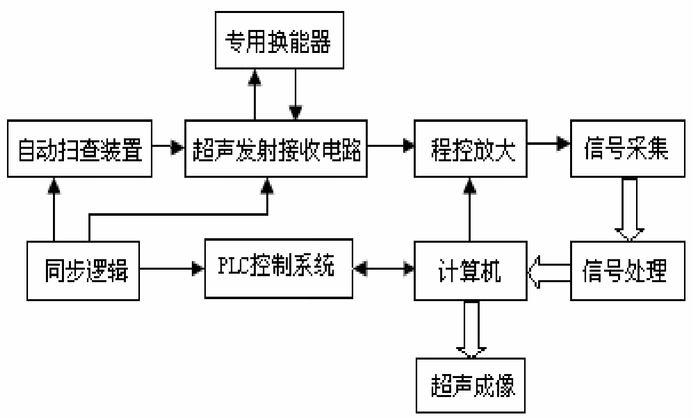


Fig 1 framework of F-scan

the signal, display the various parameters via computer.

The NDT lab of Tsinghai University has designed and manufactured the ultrasonic F scan imaging system. The system is made of automatic scanning, ultrasonic transmitter-receiver, programmable amplification and signal acquisition, computer software and all kinds of the special probes. The whole system is controlled by computer. Its workflow is as follows: synchronous logic circuits control ultrasonic transmitter-receiver circuit to ensure that the trigger, acquisition and mechanical movement of ultrasonic signal can synchronize; ultrasonic transmitter-receiver circuit receives special incentives and ultrasonic transducer signal; After filtering, program amplification, the high-speed data acquisition card for the entire Wave acquisition, signal acquisition processed into computer .Finally, ultrasonic imaging software is used for real-time imaging.

2 Focus probe

The precision of F-scan system depends on the detector's sensitivity and resolution. Various forms of focus probe are made for layered sheet. They mainly include probes through the lens of the acoustic transducer (beam probe), surface probes (Highlights probe) and apodization probe. Bunching probe and surface probe focused vibration into Gaussian distribution so that the distance become nearly uniform and in the far field larger beam precision will be acquired. Apodization probe is through the anode change's relative size so that the vibration probe can become Gaussian distribution[3], thus get the required characteristics of the sound field[4]. AS shown in Fig2, waveform and spectrum produced by the apodization probe when it is used to detect layered sheets (Frequency 12 MHz).

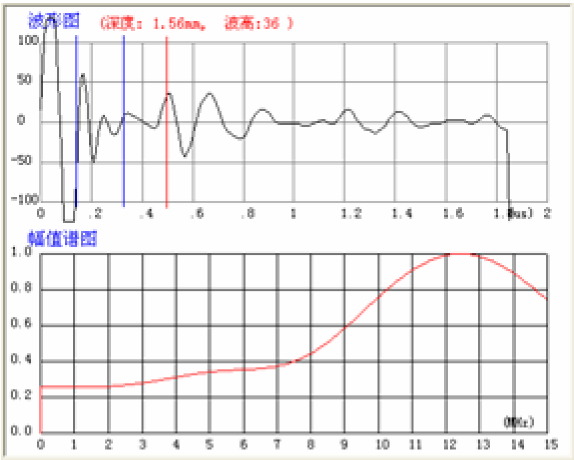


Fig 2 waveform and spectrum produced by the apodization probes

3 scan and detect the composite sheet

Layered sheet is 2 mm in thickness with two stores, whose distance respectively is 0.6 mm and 1.4mm from the upper surface. Main defect in the plate is stratification, which can occur in the upper or below layer. The purpose of testing is to detect stratification and acquire layer's depth. Responding to such testing, the artificial samples contain three layers above the surface defects and three layers under the surface defects. The diameter of the smallest defect is 1.2 mm.

The testing process of the composite sheet is: firstly open F-scan software; secondly adjust the probe's location to make echoes of interface more clearly; then identify the imaging modalities (depth or amplitude) and the gate; identify supporting factors such as the velocity, the scan distance, the scan speed and so on; finally scan and image at the same time. Figure 3 is depth image (the upper) of the artificial sample and some time-domain waveform image (the below). In the depth chart, different depth is showed in different colors within the gates: the red shows the upper layer defects, the yellow shows the below layer defects; the green shows the back wave's depth. It is B scan image at the bottom of the figure; the frame of the waveform diagram is the width and amplitude of the gate. We need to adjust the gate to the appropriate height in order to achieve better effects in the imaging before scanning. But after scanning, we need to re-adjust the height of the gate, and then re-process in order to obtain the ideal imaging effects. Figure 4 is the depth when scanning the piece and red strip defects occurs in the edge layer, which is

1mm distance to the surface.

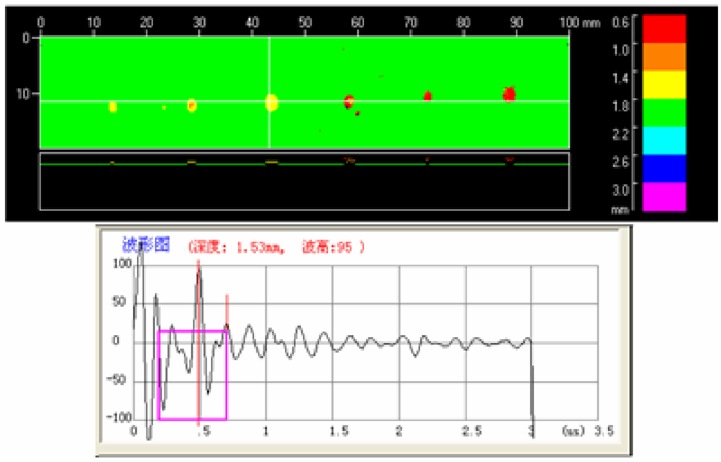


Fig3 depth image (the upper) and a time-domain waveform of the image (the below)

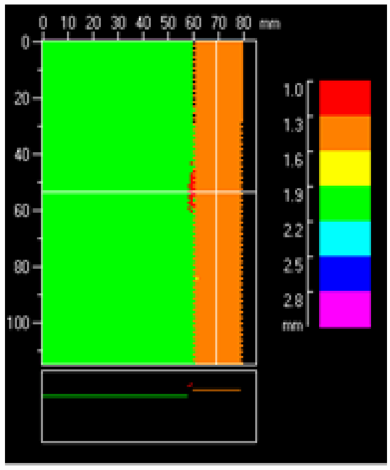
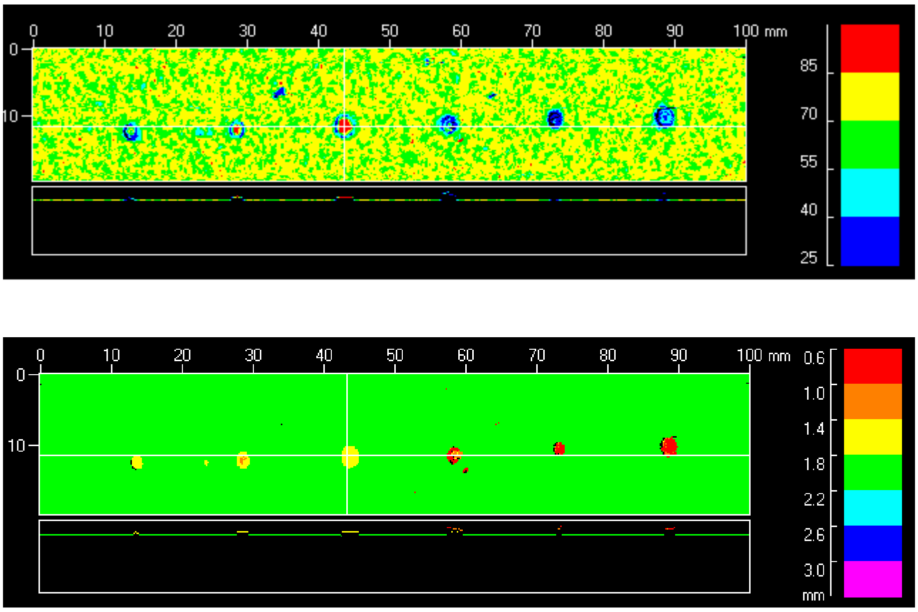


Fig4. the depth image when scanning

4． judge the defects

For the layered defects, the criterion includes amplitude judgment, location judgment and back wave judgment. F-scan imaging system has a variety of imaging methods, including C-scan imaging, phase (depth) imaging and back wave imaging. When the imaging method is phase imaging, firstly we choose a scope in a domain (depth), then give different colors to the full amplitude which is the biggest wave (defect or back wave).The different amplitude corresponding to different color in the image (shown as fig 5(a)). The defect distribution of magnitude, depth and back wave has been shown in the amplitude feature image. From the images can be seen that amplitude of the back wave is between 55% and 85% ,the wave amplitude are different. There are two defects whose amplitude is higher than 85% under layer and the upper is still higher than back wave ,but it impacts to the amplitude little. Because there are defects in the material, the amplitude of the back wave has been seriously declined. When depth imaging, we select a depth range (including the bottom generally),give different colors to the depth (phase) corresponding to the maximum of the wave and form the depth chart (see figure 5 b), showing defect wave and the depth distribution of back wave。



(a)

(b)

Fig5. amplitude (a) 和 depth (b) image of sample

For the layered defects, the size is large and the direction is perpendicular to the propagation direction of ultrasonic wave, so the back wave is seriously decline. We can estimate that there are defects through the amplitude of the back wave when the flaw wave could not be found. Figure 6 is the feature graph of the back wave. The method is to select an imaging scope (only including back wave) and set a threshold value. The points, whose values are exceeding the threshold value, are displayed in the image.

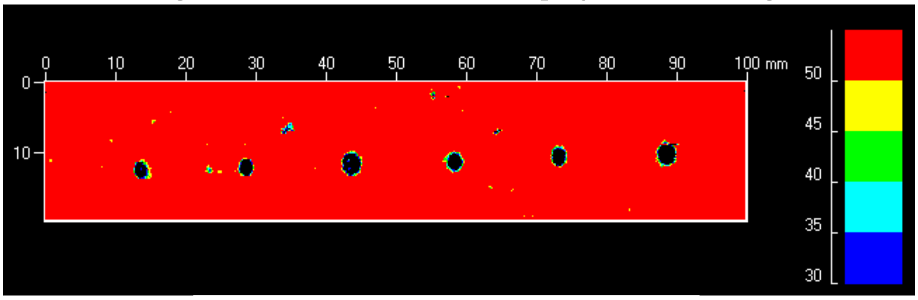


Fig 6 Feature image of the back wave

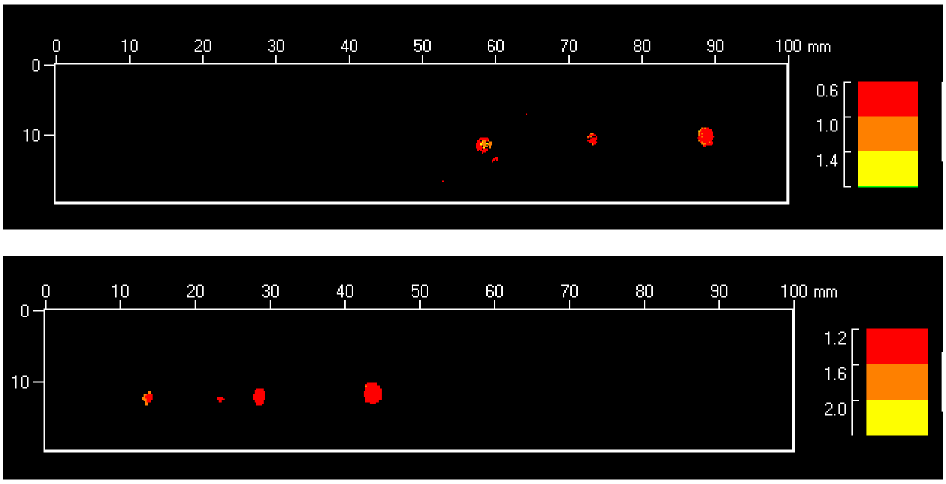
5. Ultrasonic Computerized Tomography

Computerized Tomography could be carried out by the F-scan imaging system. Computerized Tomography uses computer to reproduce the chromatogram surface or tablet of the tested object. By definition, the chromatogram of an entity is two-dimensional raster displays of the thin transect that is permeating the object. The actual transect of the object could be in any location and direction. Reflection Ultrasonic CT could be used to estimate the location and quantity of discontinuity and corrosion or erosion of metal, and determine the nature of the pores and slag. Transmission Ultrasonic CT could be used to determine the density, composition and residual stress of the material. The ultrasonic reflection chromatogram is provided by F-scan system. The size and location of discontinuity could be precisely determined through the information of sound field for different depth H of layer, the amplitude and transmission time of the echo signal. The detection signal should be analyzed from the outside to inside to recognize the type of flaw. There are some advantages of Ultrasonic Computerized Tomography for NDT: improving spatial resolution; reducing acoustic spectroscopy Dot (profiling) produced by different views on various direction; reducing image error; enlarging the dynamic region. Another advantage is that the image is digitized. The strengthen algorithm can be used to image. The best view could be got by setting the display parameters[5].

The method of CT: first chose the depth and thickness of chromatography , then adjust the height of the gate. In theory, the resolution of tomography is related to the frequency of ultrasonic signal collection. The image of the thickness corresponding to a sampling point could be displayed by Chromatography. When the thickness of work piece is constant, the ultrasonic transmission time is constant too. So when the collection frequency is increased, the resolution will be improved at the same time. Nevertheless, the resolution is related to the wavelength in actual application. Because rising-edge trigger signal is required in ultrasonic signal acquisition, and trigger point can be in arbitrary 1 / 4 wavelength of the ascending part. So, there is an error for the time of 1/ 4 wavelengths existed in the trigger time of each testing point. There is no significance for the chromatography of the thickness of a sample point. Therefore, the image with the minimum thickness (half of a wavelength) is the ultrasonic CT image. When the velocity of the material is low or the frequency of the probe is high, the wavelength will be small and the resolution of the system will be high.

The velocity of layered plate is about 6000 m / s, the frequency of transducer is 10M to 15M, the wavelength is in the range of 0.4mm-0.6mm, the highest resolution of ultrasonic CT is 0.2 mm.

Fig 7 is chromatography of the upper and lower bonding layer.The chromatography range is 0.6mm to 1.0mm and 1.2mm to 1.6mm. There are three defects existed in the upper bonding layer at the range of 0.6mm to 1.0 mm. In this layer, there is a small natural defect which could be verifed in the image of back wave (Fig 6).



(a

Fig 7 chromatogram of bonding layer

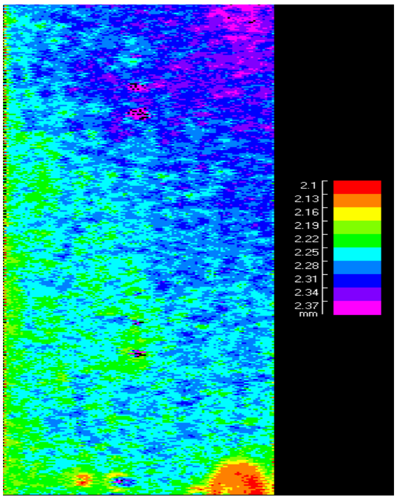
6. The measurement of the density and thickness of thin laminated plate

The frequency of the data acquisition card used in F-scan system is 200 MHz, so the measuring accuracy of the position of reflected wave is 0.03 mm. The position precision could be up to 0.01 mm through the mathematical interpolation. The position precision provides well conditions for the measurement of the density and thickness.

The main basis for density measurement are: the propagation time of ultrasonic t （time of flight) in work piece with constant thickness is inversely proportional to the velocity of ultrasonic c. When the velocity of the material is constant, t is related to the velocity of another kind of material. The relation between longitudinal velocity and the density of the material is:

$$c = \sqrt{\frac{E}{\rho}}\sqrt{\frac{1-\mu}{(1+\mu)(1-2\mu)}}$$

E is Elastic Modulus of the material, μ is Poisson ratio of the material. From this we can infer: if the time of flight of the back wave is great, the density of the material is great too. So the time of flight of the back wave is used to estimate the uniformity of the density of the material. Fig 8 is the density distribution image of thin laminated plate: the density in top right region is maximal and the density in lower right region is minimal, the density in lower left region is small. It can provide the specific value of density. The measurement precision of position of the system is 0.01 mm. There is too much difference of the density of thin laminated plate, so we use 0.03 mm space between two colors to avoid using too many colors.



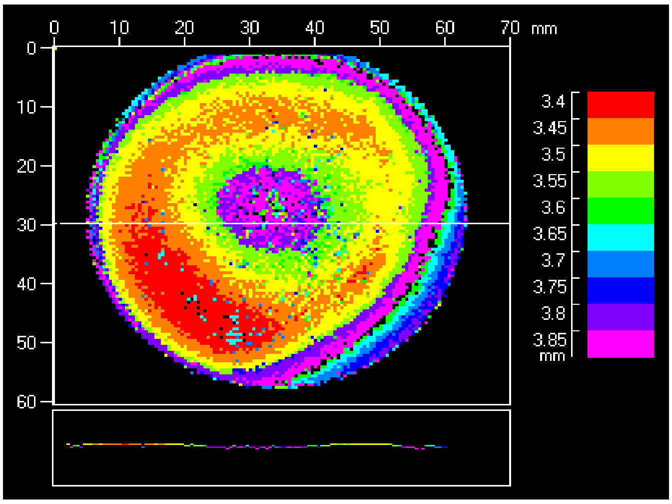


Fig8 density distribution image

Fig9 thickness distribution image

The main basis of thickness measurement are: when the total thickness of the work piece is constant, the thickness of the material is determined by measuring the position of reflected wave of binding layer, then the thickness of another material can be calculated. The sample for thickness measurement is composite wafer of cemented carbide and diamond. There are strict requirement to equipment and probe for direct measurement of the thickness, so the thickness of the diamond could be estimated by measuring the thickness of cemented carbide. Fig 9 is the thickness distribution image of cemented carbide: intermediate thickness is maximal; outward became smaller and at the edge became great again. So we could estimate that the thickness of diamond in the center is the minimal, gradually becomes greater outward and at the edge became small. The thickness of Cemented Carbide could be analyzed by tomography. As shown in Fig 10, the range of the five tomography pictures is:

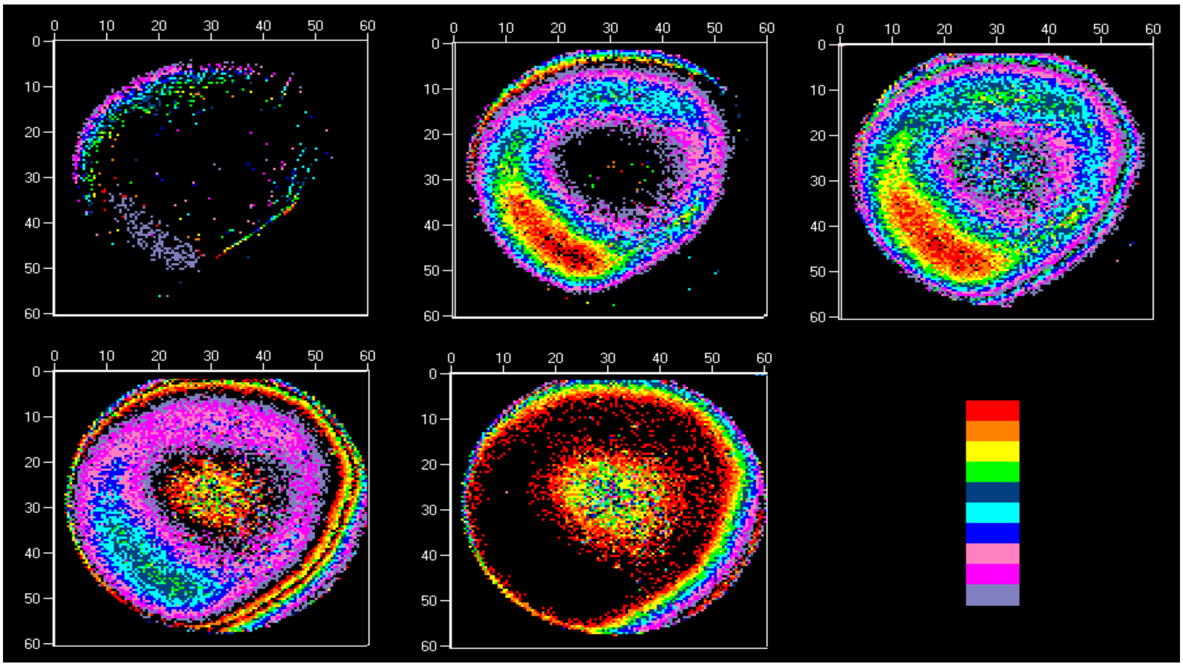


Fig 9 the thickness distribution image of Cemented Carbide

3.00mm to 3.20mm, 3.20mm to 3.40mm, 3.40mm to 3.60mm, 3.60mm to 3.80mm, 3.80mm to 4.00mm (the top left image is the first). Each color represents 0.02mm in lower right corner. From the chromatography, we can conclude that: the bonding layer of cemented carbide and diamond has been mainly distributed in the range 3.30mm to 3.90mm. The thickness distribution image of Cemented Carbide is shown in Fig 9.

7. Conclusion

On the basis of the F-scan Imaging System, the quality of the binding layer in the thin laminated plate is tested by scan imaging. The stratified defects in the upper and lower bonding layer could be detected by the system. Various mode imaging and tomography could be carried out. The measurement for the density and thickness distribution of the material could be carried out too. Now the system has been applied to industrial daily detecting of thin laminated plate.

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