The Ultrasonic Feature Imaging Testing of special structure

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Abstract:

The broadband narrow pulse self-focusing ultrasonic transducer was designed for the special structure of the column holes, and used to do the research for the testing of bonding layer of metal composite material with F-scan ultrasonic imaging system. The copper-steel boding layer of bimetal rotor is connected by diffusing welding. There may be delamination flaws existed here. The depth and range feature image can be displayed through the full wave trains time-frequency transform of the ultrasonic signal. Then the people could find out the delamination flaws of bonding layer and estimate their size by analyzing and evaluating the information of the images.

Keywords: focused transducer, feature imaging, delamination flaws, column holes

The column holes of bimetal rotor are special structure of the copper-steel bonding layer. The two kinds of metal are connected by diffusing welding. And delaminating flaw probably existed here. Because of the particular structure of column holes, domestic and international references have reported that the ultrasonic method has been used to detecting the quality of the bimetal rotor bonding layer of column holes[1]. But it is only to use ultrasonic flaw detector to carry out handwork flaw detecting, and the research for the technology of flaw detection. It could not satisfy the detecting requirements in modern nondestructive detection technology.

This thesis introduces the design of the broadband narrow pulse self-focusing ultrasonic transducer for the special structure of the column holes, and use F scanning (feature scanning) system to image the detected bonding layer of column holes.

Ultrasonic Feature Imaging adopts the method of feature scan[2]. Computer is used to do full-wave data collection of the detection signal, then collect and store the various features of the signal. Display image according to various feature of the signal after signal processing. In this way, it is better to detect and analyze the quality of the bimetal bonding layer.

1. The structure of the bimetal rotor

There are nine column holes evenly existed in the bimetal rotor. The wall of the column holes was copper-steel bonding layer, Shown as Fig.1. The thickness of the copper layer d is 1.3mm; the detecting aperture D is 14mm.

The velocity of longitudinal wave in steel is 5900 m/s, the acoustic impedance Z_2=4.6×106 g/cm2.s. The velocity of longitudinal wave in copper is 4425 m/s, the acoustic impedance is Z_1=3.94×106 g/cm2.s.

The reflectance of sound intensity of the copper-steel bonding layer is calculated:

$$R = r^2 = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2 = 0.68\%$$

According to the calculation, when the quality of the copper-steel bonding layer is good, the bonding layer reflection wave is too weak to compare with the flaw wave. And only when there are layer flaws existed in the bonding layer, the reflection wave from bonding layer is strong, i.e. flaw wave. In addition, because of the complex structure, the back wave from the surface of the copper is inordinate. So the back wave is not the detecting feature[3].

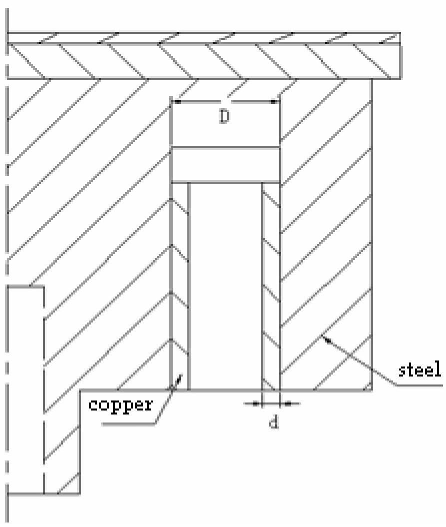

Fig 1 sketch map of bimetal rotor

2. The design of the broadband narrow pulse self-focusing ultrasonic transducer

2.1.The calculation of the center frequency of the ultrasonic transducer

The requirement of the bimetal bonding layer detecting is that estimate the size of flaw which is greater than 1mm flat bottom hole equivalent, and find out the accuracy location of the delamination flaws. According to the calculation of the longitudinal and lateral resolution capacity, the center frequency of the ultrasonic transducer is set to 10 MHz.

2.2.The design of the focus of the ultrasonic transducer and the simulated experiment

Use the plane piezoelectric ceramic ultrasonic transducer for the particular structure of the bonding layer of column holes. Utilize the different velocity between water and copper, and the focus acoustic lens to realize the focusing of the ultrasonic energy by elaborately design, within the aperture of the detecting column holes. The schematic diagram shows as Fig.2.

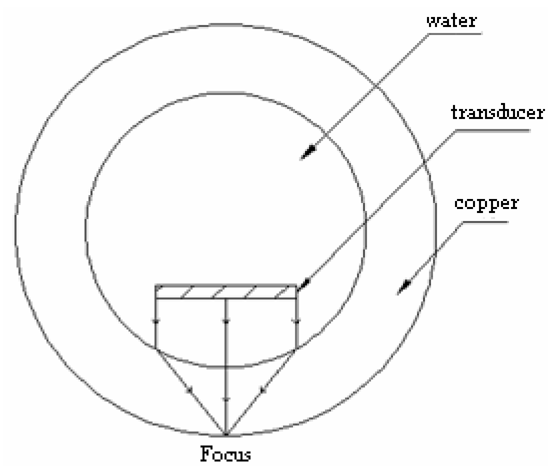

Fig 2 sketch of principle of focus

In order to verify the feasibility of this design, use the dynamic digital photo-elastic device to do a simulated experiment. The dynamic digital photo-elastic device uses the dynamic photo-elastic method to investigate the propagation and scattering field of ultrasonic in solid, and process the digital image[4].

The sketch of the sample, used in the simulated experiment, shown as Fig.3.The center frequency of the piezoelectric ceramic crystal is 10 MHz. The size is 25 mm×25 mm. The velocity of epoxy resin c_1=2700 m/s; the velocity of optical glass c_2=6000 m/s.

According to the concept of equivalent sound-path:

$$\frac{d_1}{c_1} + \frac{x}{c_2} = \frac{d_2}{c_1} + \frac{d}{c_2}$$

Here, the sound-path of one side is calculated according to the wave from the center of crystal. The sound-path of another side is calculated according to the wave from the middle of crystal. The focus is at 9.56mm by previous Equation.

Put the sample on the dynamic digital photo-elastic device and do some experiment, the images show as Fig.4. The Fig.4 (a) is the image before focusing, Fig.4 (b) is the image of focusing, and Fig.4 (c) is the image of focused ultrasonic beam. From a group of images, the ultrasonic wave appears the phenomenon of focusing at 8-10 mm. Therefore, the results of the experiment are consistent to the theoretical calculation.

The material of the crystal is PT, and the parameters of the piezoelectric crystal are as follows: frequency is 10 MHz, thickness is 0.218mm, the relative dielectric constant is 1500F/m, and diameter is 6mm. The backing material is epoxy-tungsten, which the epoxy resin filled in tungsten powder and solidified. In the epoxy-tungsten, the solidified epoxy resin which is used to be the frame provides the Yang-modulus of the material, and determines the velocity of the ultrasonic in the material. The tungsten powder which is used to be the filling provides the high density of the material, and also dispersion and absorbs the acoustic wave.

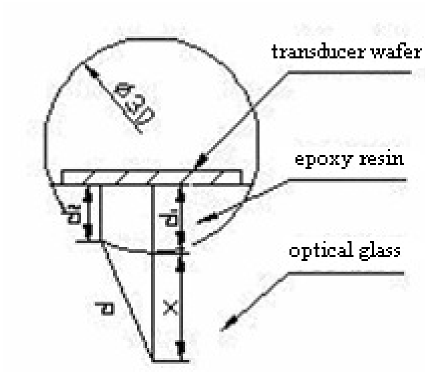

Fig 3 sketch map of the simulated experiment sample

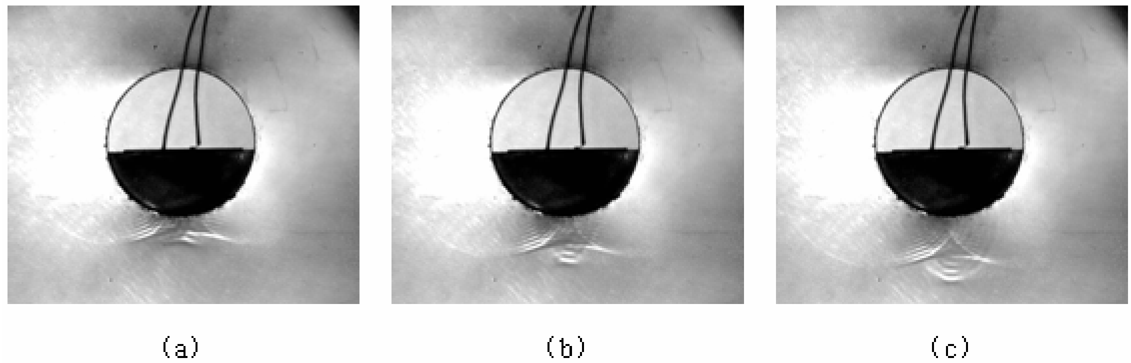

Fig 4 the images for the focus process of the ultrasonic transducer

Verified by the experiment, the wave train of the transducer is narrow and has only one and a half periods. And the peak to peak value of the back wave is great. Therefore, the 10 MHz ultrasonic transducer has excellent properties and meets the design requirements. It can be effectively utilized to detect small flaws in ultrasonic imaging.

3. The technology of ultrasonic features imaging

The Feature Scan Imaging is a new technology that developed from the traditional C-Scan Imaging in 1980s. This method is put forward and utilized by United States Air Force Engineering Center in 1980.It adopted the method of feature scan, used computer to do full-wave data collection of the detection signal, then collect and store the various features of the signal. Display image according to various feature of the signal by signal processing. Except for detecting part flaws; it can carry out spectrum analysis and digital filter. The flaws can be recognized by collection and reconstruction of various features. Thus, the quantitative accuracy could be greatly improved[6].

The features introduced in f-scan include two aspects: one is the characters of the ultrasonic waveform, which contain the rise time, fall time, pulse period, and spectrum characteristic; another is the characters of the flaw, which contain type, shape, and size of the flaw.

The key of F-scan is the research, collection and determination of the feature of the flaw in the tested piece[8].

4. The feature imaging testing for the bimetal bonding layer of column holes

There are delamination flaws exist in the bimetal bonding layer of column holes. The purpose of testing is to examine and present the depth of the delamination flaws. An automatic scanning equipment with three servo mechanism was designed for the particular structure of column holes. The process of testing is: first, open the software for testing, adjust the position of the probe until the upper and lower interface echo is clearly displayed in A-scan. Second, chose the display mode (depth or amplitude) and set the value of the gate. Then start scanning the column hole, the image of the column hole is displaying at the same time.

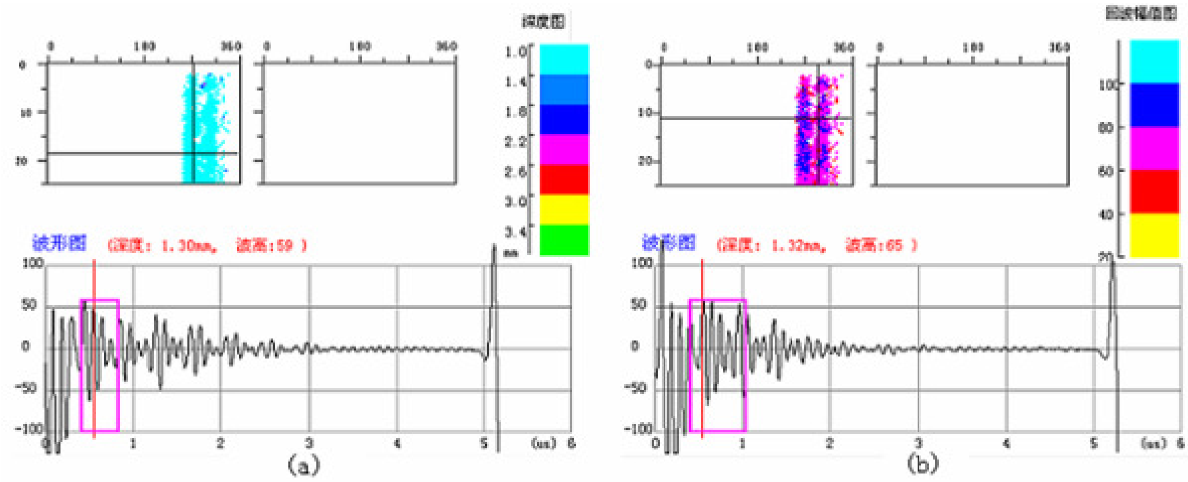

Fig 5 the depth and amplitude feature images

The depth (phase) and amplitude feature images show as Fig.5. The two typical holes in Fig.6 are chosen from nine holes. The point will be colored in the image (If there are any waves, which the amplitude is out of the range of the gate and the depth is in the range of the gate, existed in this point.). The color corresponds to a range of detecting area in the color-block. As show in the depth image, the area without color represents connecting well. Because most of the ultrasonic wave is through the bonding layer and the back wave is weak. The area with color shows that there are delamination flaws existed in copper-steel bonding layer. Because there are strong reflection existed. The waveform in Fig.5 (a) shows that the character of the ultrasonic wave at the crossing point is: the depth is 1.30mm, the height is 59, and there are some waves followed the defect wave (this is the character of welding-off). It shows that there is 1.30mm between the delamination flaws and the surface of copper. The Fig.5 (b) is amplitude feature image. The delamination flaws existed in the colored area. The value of echo amplitude corresponds to the condition of delamination. The waveform in Fig.5 (b) shows that there are delamination flaws existed and its depth is 1.32mm.

The Fig.5 (a) and Fig.5 (b) show that there is an area existed delamination flaws in the left column hole , the circumferential length of this area is about 90°, and the height of this area is about 18mm.

5. Conclusion

The particularly designed ultrasonic transducer, special scan equipment, and ultrasonic feature imaging testing system are used to detect the particular structure of bimetal column holes and image in various ways. The size, shape and position of the delamination flaws in the bonding layer can be accurately tested and measured. This method has been applied in the daily detection work for the quality of bonding layer in the column holes of bimetal rotor.

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