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Ultrasonic Feature Imaging System for Testing Bimetal Rotor Clad Layer

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Abstract:

An ultrasonic feature scan imaging system used for testing delamination flaw probably existing in the bimetal rotor clad layer was studied and developed. The bimetal rotor with nine column holes can be tested automatically. All the wave train of testing result will be saved in computer for post processing. There are various imaging modes including depth imaging and amplitude imaging, to find delamination flaws accuracy and estimate their size. Imaging experiments for actual work piece was done using the system, and all kinds of feature information were collected. The system has high stability and repeat-ability.

Keywords: Feature Scan, imaging, delamination flaw, column holes

1. Introduction

The bimetal rotor with nine column holes is compounded with steel and copper, using method of diffusion bounding. The normal flaws existing in melt welding do not exist in diffusion bonding. But joint badness flaws present in diffusion bonding for some craftwork reasons, such as delamination flaw. There are papers about testing bimetal rotor using ultrasonic method, but they are only discussing about the testing method. And all these testing are manually without scanning and imaging. [1] These methods are no longer enough for non-destructive testing, because people need not only the result of having flaw, but also the detailed information about the flaw, including size, location, and more easily understanding pictures in order to have reliable analysis result.

An ultrasonic feature scan imaging system dedicated for testing delamination flaw probably existing in the bimetal rotor clad layer was studied and developed. This system can be used to solve real problems in testing department.

Doctor Chern James firstly talked about feature scanning (F Scan) technology. [2] This technology uses the method of scanning, and all the wave train of testing result will be saved in computer for post process. Ultrasonic waves have many features: rise time, decline time, pulse period and frequency feature. There are various imaging modes for searching delaminating flaws, and estimate their size. Through analyzing all kinds of features, results will be got in fixed quantity by colorful pictures.

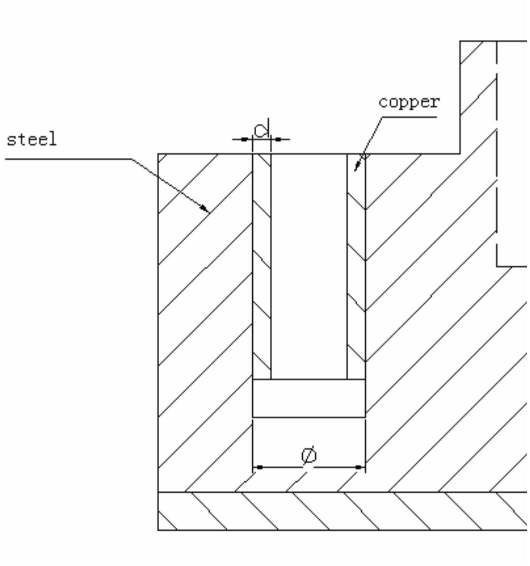

Figure 1. Column holes work piece

2. Testing object

Figure 1 is column holes work piece. The depth of copper d=2.5mm, and the diameter of hole φ=11mm. 9 column holes are separated evenly.

Copper's density is 8.9g/cm3, and its velocity of sound is 4400m/s. Copper's sound feature impedance Z1=3.9×106g/cm2.s. Steel's density is 7.8g/cm3, and its velocity of sound is 5900m/s. Steel's sound feature impedance Z2=4.6×106g/cm2.s. [3] Using these data, we get the sound strength reflectivity of copper and steel bimetal is $R = r^2 = (\frac{1 - Z_2/Z_1}{1 + Z_2/Z_1})^2 = 0.7\%$.

From the formula, if the combination of copper and steel is good, the reflecting wave from the combination layer will be very week. But if there are delamination flaws on the combination layer, there will be strong reflecting wave. This wave is defective wave. Meanwhile, since the thickness of copper and steel is different from different direction, the reflecting wave from copper surface is not regular. So the wave can not be used as testing feature.

3. System structure

In order to achieve auto testing and scanning feature, the main system consists of three parts: mechanical and electrical controlling subsystem, ultrasonic sensor and transmitting and receiving subsystem, and signal processing subsystem.

Figure 2 is the system structure frame.

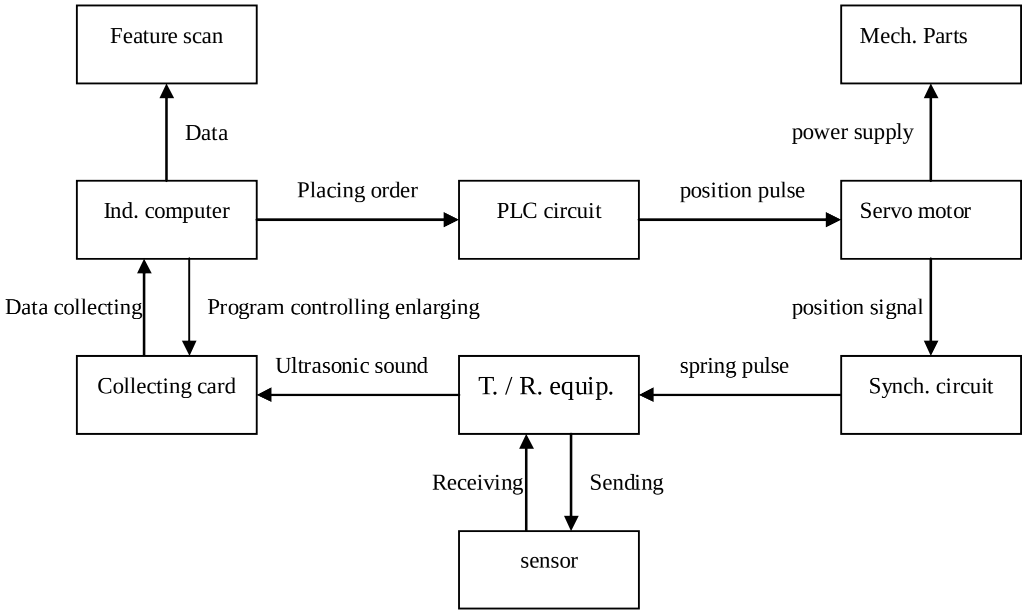

Figure 2. System structure frame

3.1. Mechanical and Electrical controlling subsystem

Figure 3 is the mechanical structure sketch. The diameter of the rolling table φ=300mm, and the available journey of sensor is 200mm.

Before testing, fix the work piece at the center of the rolling table, and adjust the sensor's position to be straight with the column center.

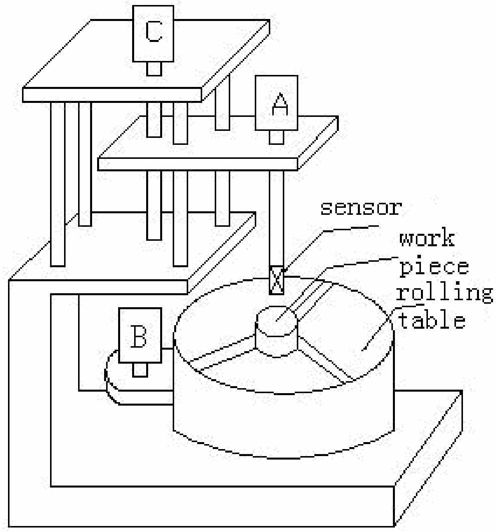

Figure 3. Mechanical Structure

After that, sensor is driven by servo motor C downwards. Meanwhile, it is circulating driven by servo motor A. Servo motor A will circulate clockwise in one circle and anti-clockwise in the next circle, avoiding the twist of sensor's cable.

After testing one column, motor C will go upwards with sensor. Then motor B will rotate 40 degree with rolling table (evenly divided by 9) to test the next column.

Server motor system is the center of mechanical and electrical controlling subsystem. Considering the dynamic factor, such as angle speed ω(t), angle acceleration α(t), torque T(t), biggest load power P, precision, controlling way, signal feedback system (rotate encoder) and so on, at last, Yaskawa ∑-Ⅱ VC sever motor. This sever motor has increment encoder, and advanced electrical gear adjust function.

The circuit controlling part is mainly composing two parts: PLC (programming logical controller) and PCB circuit. PCB circuit includes power supply, sever motor control circuit, PLC connection circuit and synchronization logical circuit. The PCB circuit has good stabilization.

In the PCB circuit, synchronization logical circuit is relatively complicated. The location signal outputted by rotate encoder is thread driving, so the signal is easily disturbed during long transportation. In order to eliminate this disturbing, firstly using thread driving receiving chip to differential enlarge location signal. Then use other chip to adjust the signal and counterchange the frequency by calculating. The signal after counterchange will go through monostability trigger for pulse width adjusting, in order to have several microsecond pulse width signal, as ex trigger for data collecting card.

Mitsubishi FX1N 60MT PLC is choused. This PLC has 32 input and 24 output. There are two high speed pulse output, and the highest frequency is 100KHz.

3.2. Ultrasonic transducer, transmitting and receiving device

A broadband pulse ultrasonic transducer using in thin sandwich plate testing are designed and accomplished accordingly. The frequency is 10MHz, and focus distance is 20mm. In order to be smaller than the column, the diameter of transducer is 7mm.

Figure 4 is the wave picture and amplitude frequency picture of the ultrasonic transducer using in the column testing. In the picture, the first two pulse width is less than two period. So, the transducer has high differentiated ability and makes sure to pick-up all useful information.

A digital ultrasonic transmitting and receiving system is used. This device's indicator is:

- transmitting voltage is 0-400V, and the pulse width is adjustable
- transducer frequency scope is: 1-20MHz
- receiving scope is: 0-35MHz
- amplifier scope is: -49dB~+59dB RF, and the step is 1dB
- one 10MHz lowpass filter and one 1MHz highpass filter

3.3. Signal processing subsystem

Signal processing subsystem includes high speed data gathering card and software system.

The high speed data gathering card's indicator is:

Communicating way:	PCI
Sampling differentiate:	8 bit
Highest sampling frequency:	100MSPs
Data length:	512kBytes
Tiggering way:	EXT, Signal triggering and software triggering

Program controlling amplifier: amplifier scope is from -10dB to 30dB, step is 1/256

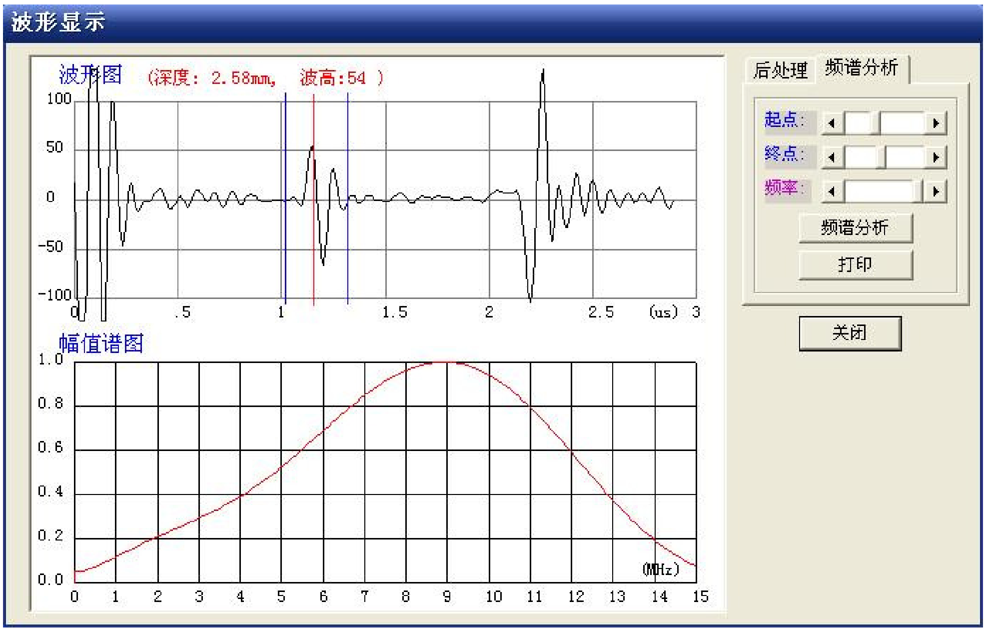

Figure 4. Transducer's wave and frequency

Software system is based on Windows XP, and developed by Visual Basic. The interface between people and system is friendly. The software system has a lot of functions and is easy to operate.

After all the testing data is collected by data gathering card, software will analyze these data and pick-up data feature. There are several main features: (1) reflecting wave amplitude; (2) reflecting wave phase; (3) reflector's geometry shape; (4) reflector's space amplitude distribution; (5) bottom interface's amplitude; (6) bottom interface's wave phase; (7) upper interface's wave amplitude; (8) upper interface's wave phase. Feature (1) to (4) are compulsory to determine a flaw, so they are major feature. (5) to (8) are used to test the work piece's upper and bottom interface's distance, so they are minor features.

Software system will plot feature chart using testing data, including:

1. phase (depth) feature chart: pick-up distance between flaw and interface from testing data, and use different color to present different distance;
2. amplitude distribution chart: pick-up reflecting amplitude as feature from testing data, and use different color to present them;
3. ultrasonic stratum (CT) display: present reflecting amplitude by workpiece depth layer by layer. In this chart, testing result for any section of workpiece can be displayed. This can not be done is traditional testing method.

4. Imaging Testing Experiment

A sample work piece was testing. On column hole of the work piece has delamination flaw. The parameter of scanning is: column hole diameter-10.8mm, column hole depth-20mm, scanning 68 points every circle (0.5mm between points), rotating speed-60 r/m, and sampling speed-100M. The velocity of sound is 4500m/s. The strobe range is from 2.0mm to 3.5mm, and the strobe value is 15.

Figure 5 and figure 6 are the depth feature chart and amplitude distribution chart. We take two holes of the nine holes. In the chart, every wave in the strobe range which is bigger than the strobe value, will be lined out, and the color is from the right side.

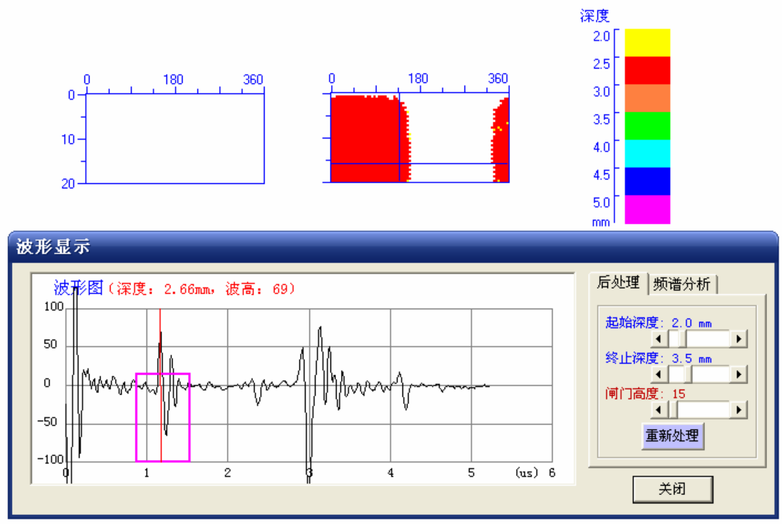

Figure 5. Depth feature chart

In the depth feature chart, no color means the point is well welding, so ultrasonic will go through the copper and steel compounded material, and the reflection is very few. But the colorful area means there is some delamination flaw, so the ultrasonic will reflect apparently. The following figure shows the wave of the point marked by reticle. From the data we can see there is delamination flaw at 2.66mm depth. (Because the setting ultrasonic speed is different from the real one, so the result is a little bit different from the real depth.)

In the amplitude distribution chart, no color means that the point is well welding, but the colorful area means there is some delamination flaw, so there is reflecting wave from the compounded surface between copper and steel, which is bigger than the strobe value. Different color means different reflection value, and bigger value means bigger flaw. The following figure shows the wave of the point marked by reticle. From the data we can see there is delamination flaw at 2.656mm depth.

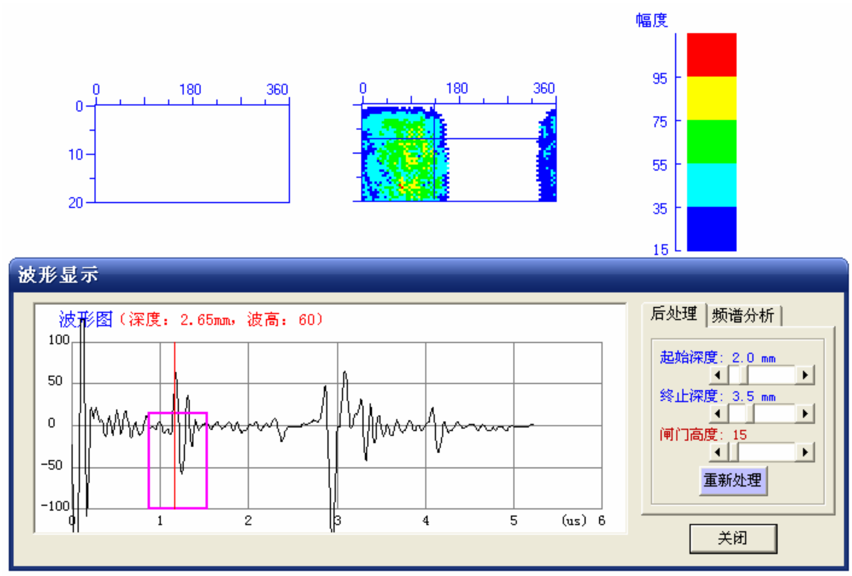

Figure 6. Amplitude distribution chart

From the two charts, it is sure that there is one delamination flaw in the column hole, and the flaw's circle length is bigger than 180°, and its axis length is almost 20mm.

5. Epilogue

This ultrasonic feature scan imagining system is specifically designed to solve the actual problems happened during the testing procedures of the industrial departments, and it can automatically scan and image the column holes whose diameter only 11mm, in and indicate the separating layer weaknesses in the copper and steel bimetal composite layer. This system works stable, has high precision in finding the weaknesses, and can be relied on and working many times. After certain improvements, it can surely be used in more circumstance in the testing of small diameter composite tube material.

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