Insepection of 300 mm Thick Titanium Plate Using Annular Array Probe

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Abstract

Due to its structure, annular array probe has a very good focusing performance along axial direction, so it is very fit for thick parts inspection. In this paper, a special annular array probe was designed through simulation and manufactured. Upon this, a multi-zone inspection proposal of 300 mm thick titanium plate was developed, where Dynamic Depth Focusing (DDF) method was considered to improve the performance and inspection speed. Then an actual test was implemented to inspect a 0.8 mm diameter flat-bottom-hole located at the bottom of a 300 mm thick titanium plate, the signal to noise ratio is really high. That means the proposal is feasible.

Keywords: Annular Array Probe, Simulation, Multi-zone Inspection, Dynamic Depth Focusing (DDF)

1 Introduction

Titanium alloy has been widely used in the field of aviation and shipbuilding since the 60s of last century, and its proportion is still rising because of its high strength, corrosion resistance, high temperature resistance and so on. The most common used titanium parts are forgings and weldments, it may produce defects in the process, such as lack of fusion, porosity and so on, resulting in the decline of the overall mechanical properties of the part, and even serious accidents [1-3].

For thick titanium alloy parts, it always use conventional immersion focusing probes to do multi-zone inspections to get a good sensitivity and defect resolution. But this method requires frequent replacement of the probes, so the detection efficiency is reduced. Phased array ultrasonic detection is a new technology developed in recent years, it can make the sound beam focuses in different depths through applying different time delays to different elements. It provides a new solution for the detection of thick titanium alloy parts [4-6].

2 Design of Annular Array Probe

There are many types of phased array probes, where linear array probe and annular array probe are suitable for thick titanium plate detection. Linear array probe can only focus the beam in the incident plane, when annular array probe can perform 3D focusing along axis due to its structure.

The elements of annular array probe is a series of concentric rings, see Figure 1. Figure 2 shows the results of surface echo simulation of an annular array probe and a conventional probe. The surface echo of annular array probe is much wider and noisier than conventional probe, so the surface dead zone...
would be bigger, and the near surface defects may not be detected. Thus, in this proposal, a specific probe is designed, where a conventional focusing probe is inserted in the middle of an annular array probe to improve the resolution of near surface defects. In order to get a good sensitivity, both the frequencies of annular array probe and conventional probe are 10 MHz, where the element number of annular array probe is 31.

Figure 1: Schematic diagram of annular array probe.

a. surface echo simulation result of annular array probe (left is B-scan, right is A-scan)

b. surface echo simulation result of conventional probe (left is B-scan, right is A-scan)

Figure 2: Surface resolution comparison of annular array probe and conventional probe.

3 Proposal of 300 mm Thick Titanium Plate Inspection

3.1 Dynamic Depth Focusing (DDF)

Phased array ultrasonic technology can focus beam in different depths through applying time delay to elements, this time delay includes transmission delay and reception delay, see Figure 3.
Dynamic depth focusing is a kind of special reception focusing mode, its transmission is still single point focusing, but when receiving, by applying a set of delay laws, multiple reception focal points are formed in a certain range, and though the sensitivity and resolution in this range are improved. The working principle as shown in Figure 4.

Due to the advantages of easy settings, small amount of data and small beam size of DDF, the resolution of the image is higher and the results is better than conventional phased array methods.

3.2 Proposal of Multi-Zone Inspection

For thick parts, multi-zone inspection would be performed. According to the requirements, the sensitivity variation within each zone should be within 6 dB. Simulation comparison was done to optimize the proposal, including DDF range optimization and focal point gap optimization. The final one is below.

Zone 1: 0-29 mm, conventional immersion focusing probe;

Zone 2: 29-41 mm, transmission focusing at 35 mm depth, and DDF range from 29-41 mm, gap 4 mm.

Zone 3: 41-60 mm, transmission focusing at 50 mm depth, and DDF range from 40-60 mm, gap 6.7 mm.
Zone 4: 60-90 mm, transmission focusing at 75 mm depth, and DDF range from 60-90 mm, gap 10 mm.
Zone 5: 90-150 mm, transmission focusing at 120 mm depth, and DDF range from 90-150 mm, gap 20 mm.
Zone 6: 150-300 mm, transmission focusing at 230 mm depth, and DDF range from 150-300 mm, gap 40 mm.

The beam distribution in each zone as shown in Figure 5, -6 dB beam field of zone 1 (0-29 mm) is 0-36 mm, -6 dB beam field of zone 2 (29-41 mm) is 29-41 mm, -6 dB beam field of zone 3 (41-60 mm) is 40-60 mm, -6 dB beam field of zone 4 (60-90 mm) is 59-92 mm, -6 dB beam field of zone 5 (90-150 mm) is 89-156 mm, -6 dB beam field of zone 6 (150-300 mm) is 138-300 mm.

Figure 5: Sound pressure distribution curve along beam axis in each zone.
From the sound pressure distribution curve, the -6 dB range of each partition can be covered with each other to meet the requirements.

4 Proposal Verification

The proposal of multi-zone inspection has been determined by the previous simulation, and the following two steps are verified by simulation and experiment respectively.

4.1 Simulation Verification

In each zone, 0.8 mm diameter FBH were added at different depths. In zone 1 (0-29 mm), the depths of defects are 10 mm, 20 mm and 30 mm. In zone 2 (29-41 mm), the depths of defects are 29 mm, 33 mm, 37 mm and 41 mm. In zone 3 (41-60 mm), the depths of defects are 41 mm, 47 mm, 53 mm and 59 mm. In zone 4 (60-90 mm), the depths of defects are 60 mm, 70 mm, 80 mm and 90 mm. In zone 5 (90-150 mm), the depths of defects are 90 mm, 110 mm, 130 mm and 150 mm. In zone 6 (150-300 mm), the depths of defects are 150 mm, 185 mm, 220 mm, 255 mm and 290 mm.

The inspection simulation results are shown in Figure 6 (left image is B-scan, horizontal axis is scanning trajectories, vertical axis is depth. Right one is dynamic curve along propogation, it shows the relative amplitude of each defect. Its horizontal axis is propagation time, vertical axis is amplitude).

![Image a. inspection simulation result of zone 1 (0-29 mm)](image)

![Image b. inspection simulation result of zone 2 (29-41 mm)](image)
It can be seen that in each zone, the amplitude difference of all the defects are less than 6 dB.

4.2 Actual Inspection Verification
The above simulation only proves that the proposal is theoretical feasible, but the actual detection sensitivity of 0.8 mm flat bottomed hole needs to be verified. Therefore, after customization of the annular probe that was designed in the simulation, the following test was done: a 0.8 mm diameter FBH was processed in a 300 mm thick titanium alloy plate at 297.5 mm depth, and the previous scheme was implemented to detect it. The test results is shown in Figure 7.

![Figure 7: Inspection results of 297.5 mm depth FBH defect.](image)

It can be seen the defect echo is very obvious, and the SNR is bigger than 15 dB.

4 Conclusion

For 300 mm thick titanium alloy parts, there is no mature inspection technology. In this paper, a multi-zone DDF inspection proposal using annular array probe was developed through simulation and then verified in actual test. It can meet 0.8 mm FBH sensitivity requirements, and the SNR is really good, so the proposal is feasible.

References


