ULTRASONIC INSPECTION OF THICK PARTS WITH PHASED ARRAY DYNAMIC FOCUSING

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1. Introduction

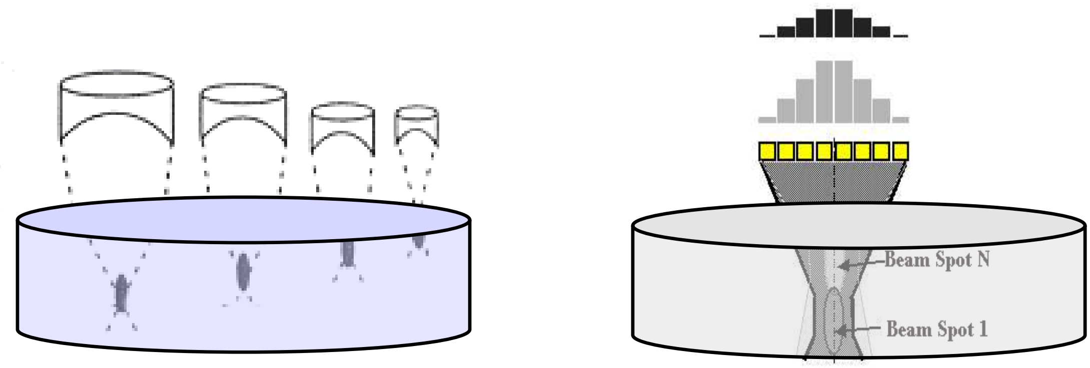
Some crucial thick parts, such as aero-engine disks, usually require high inspection sensitivity to test small defects at all depth of the parts. With conventional ultrasonic inspection method, a variety of monolithic focus transducers have to be used separately to test different depth scope of the thick part, based on the theory that the monolithic transducers with different element diameters and focusing properties have different inspection capabilities at different depths within the materials. With the increase in depth of the inspection zone, the transducers with larger element diameters should be used to provide concentrated narrow beam and enough acoustic energy. That's the reason that the same surface of a part has to be scanned many times to insure the coverage of the whole thickness of the part by high sensitivity ultrasonic beam, which results in a low inspection efficiency. The phased array dynamic focusing technique may be a good solution to improve the efficiency by focusing over the whole thickness in one scan and simply using one transducer.

In this paper, the research work on using phased array dynamic focusing technique to test thick parts is presented. Focal law of phased array testing determined with CIVA sound field simulation and calculation software is illustrated on emphases and demonstrated with experiment results. Typical application of phased array dynamic focusing with high sensitivity and rapid scanning on a thick disk is described and the result of comparison with conventional multi-zone focusing technique is also presented.

2. Phased Array Dynamic Focusing

Usually narrowing the beam diameter to a focal point increases sound energy per unit area within the focal zone and thus improves sensitivity to small reflectors. In conventional transducers, focusing is usually realized by a refractive acoustic lens, while in phased array transducers the sound beam is shaped electronically by means of phase-shifted pulsing of transducer elements. The beam can be electronically focused at a desired depth, as shown in Fig.1.

To avoid the lack of efficiency caused by repeated scanning of transducers on different focus depth, the advantage of phased array transducer on fast changing of focus electronically should be used. But the multi-depth focusing mode—the transmitting pulse and receiving pulse are focused at the same point at each depth—makes the focal law very complex and has to deal with a large amount of test data which may limit the speed of scanning.



a．Conventional transducers　　　　b. Phased array focusing

Fig.1 Multi-zone focusing inspection of disks

Another phased array focusing mode is depth dynamic focusing, in which the transmitting pulse is focused at a desired point in the part and the receiving pulse is re-focused not just on a specific point but on a number of points in the predetermined scope by different time delay patterns applied to the receiving pulse, shown in Fig.2. This approach of dynamic focusing has relatively simple focal laws resulting in a smaller amount of data to be processed and a faster inspection. On the other hand, the smaller the beam diameter of received sound beam on the focus is, the higher the image resolution can be achieved.

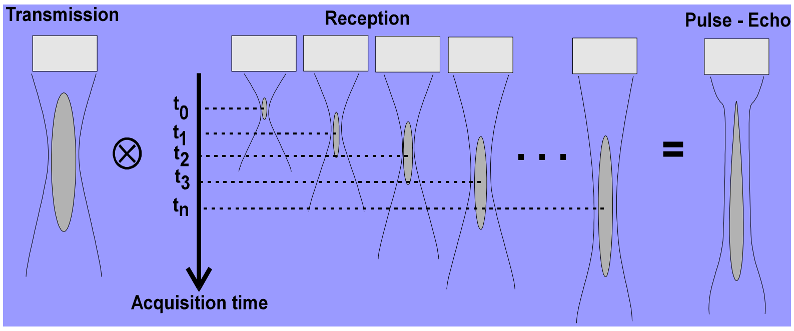


Fig.2 Dynamic focusing sketch

Due to the limited focal zone of focused sound beam of the transmitting pulse, the sensitivity outside the focal zone may be very low using the above-mentioned dynamic focusing, shown in Fig.2. If the thickness of the part increases, a better sensitivity is required, several focal laws of dynamic focusing can be combined to allow transmitting beam focusing at different depths.

The experiment in this paper will show the use of this kind of dynamic focusing mode.

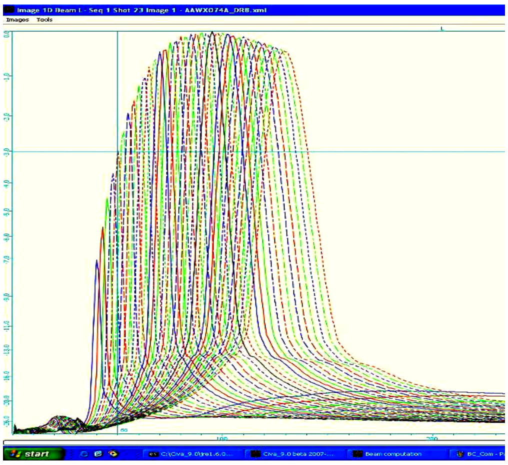
3. Focal Law design method

The phased array transducer used in this paper is of annular type with a nominal frequency of 10MHz and element diameter of 32mm composed of 14 annular elements and a removable central element (focal length 76.2mm).

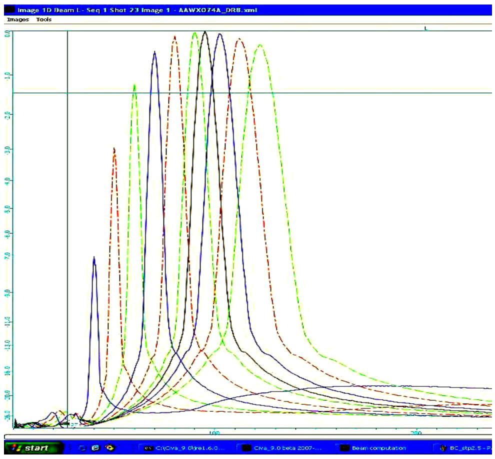
The interval between the focus (step) is a key parameter of depth dynamic focusing inspection. According to the principle of focusing, the sound intensity is much higher on the focus and the sound intensity is reduced rapidly with the increase of distance from the focus. For the same diameter of transducer, the focal field depth increases as the focal length increases. Therefore the step should be varied with the increase of depth in the consideration of the overlap of the focal zone according to the sensitivity requirement. If the step is too large, the area between the focal zones will be low sensitivity areas. If the step is too small, the number of the focal laws will be larger and longer inspection time is needed. Simulation and calculation software is a good tool for design of focal laws to get suitable step.

The following is to describe the approach of design for the focal laws. Sound field with different steps is obtained with CIVA simulation and calculation software. From the results, the sound intensity distribution with depth is shown and whether the step is suitable or not is identified clearly. Fig.3 shows the simulation results with CIVA. When the step is 2.5mm, in the depth range of 40 to 100mm, comparing to the focus point, the intensity drop of the intersection is less than 2.5dB, greater than that in the range above 100mm in which the intensity drop is less than 1.5dB and the envelop of the intensity is smooth. When the step is 10mm, there are less focuses than that of the step 2.5mm and the intensity on the beam axis changes obviously. From the Fig.3 we can also see that with the depth increase, the focal zone gets longer and the intensity drop of the intersection is less. Thus, the step should not be selected too large at small depth, while the step can be increased at large depth.

The experiment results shown in Fig.4 are consistent with the simulation.



a. Step 2.5mm



b. Step 10mm

Fig.3 Simulation of sound intensity distribution on the beam axis with different steps in water

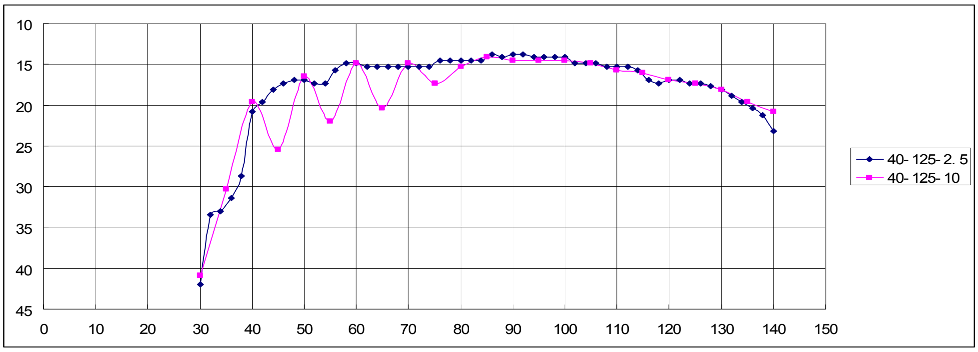


Fig.4 Experimental results of sound intensity distribution on the beam axis with different steps in water

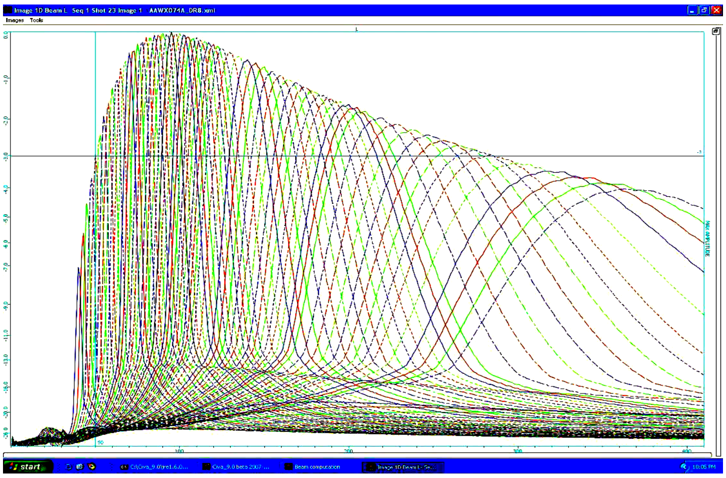


Fig.5 Simulation of sound intensity distribution on the beam axis with changing steps

Based on the steps design results, the combination of different steps with different depths is provided to form a focal law. The sound intensity distribution in Fig.5 is an example: in the range 40-125mm, the step 2.5mm, 125-220mm, the step 5mm, 220-290mm, the step 10mm, 290-382mm, the step 17.5mm. In the entire depth range, sound intensity reduction is less than 6dB.

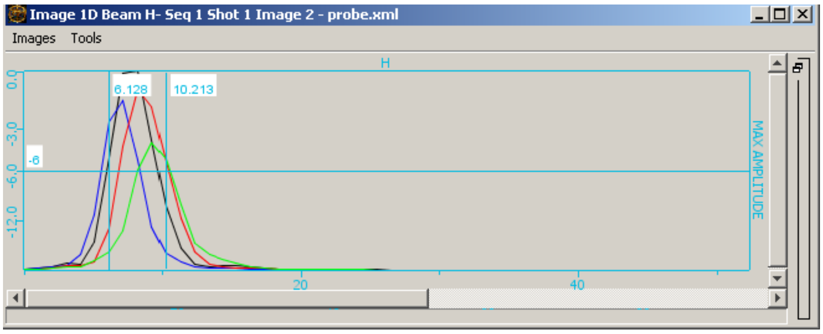
In conclusion, the simulation is a very useful for focal laws design.

4. Experiment and Results

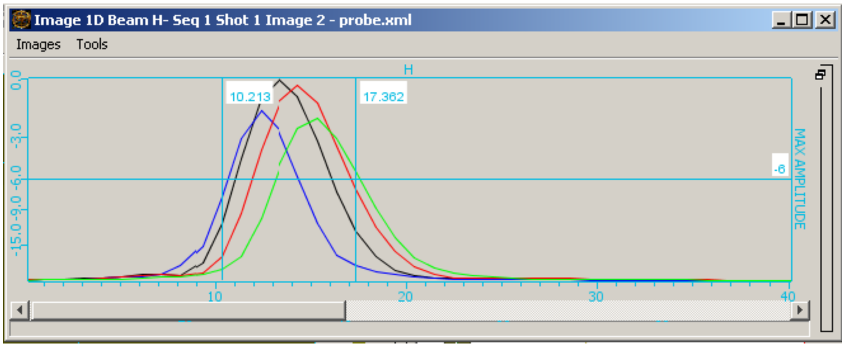
A φ75×80mm super alloy sample is tested using depth dynamic focusing with the focal law design mentioned above. Transmitting pulse is focused at different depth and received pulse uses dynamic focusing.

4.1 Focal laws design

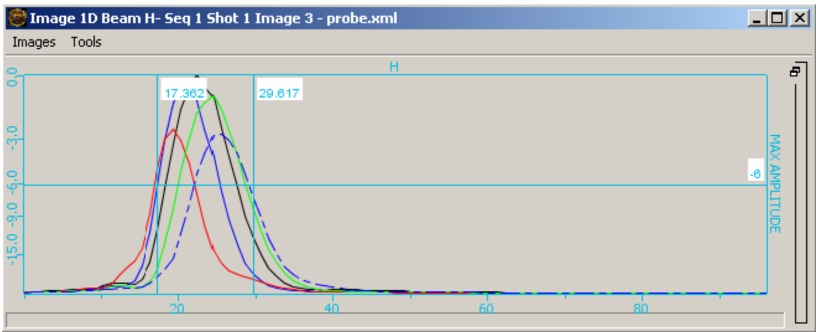
According to sensitivity requirement (60mm water distance, the sensitivity change on each focal zone is less than 6dB). Simulation of the dynamic focusing law is shown in Fig.6.



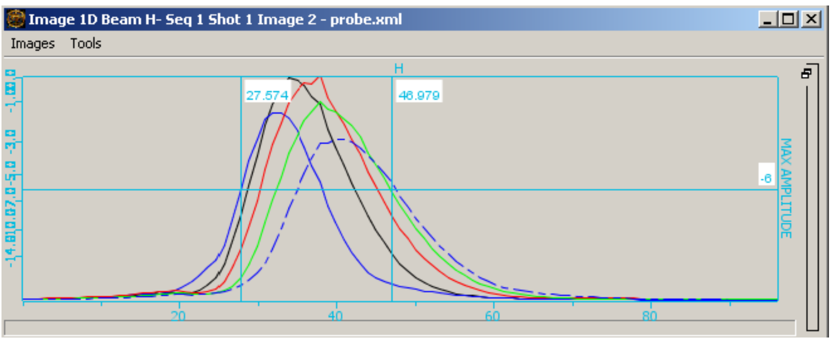
a. Transmitting pulse focused on 10mm, received pulse dynamic focusing, step 1.667, test range 8-13mm.



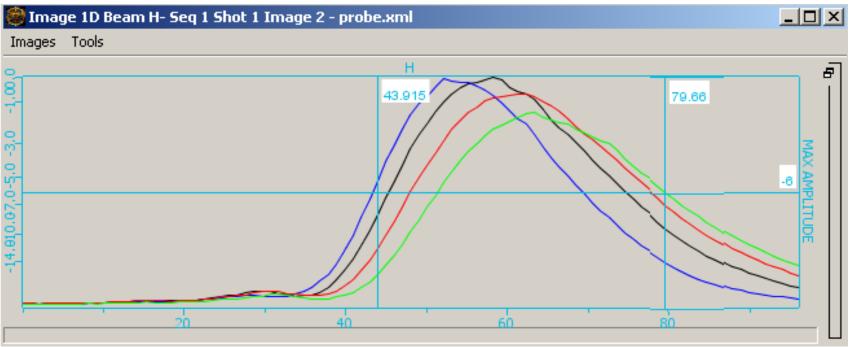
b. Transmitting pulse focused on 16mm, received pulse dynamic focusing, step 2, test range 13-19mm.



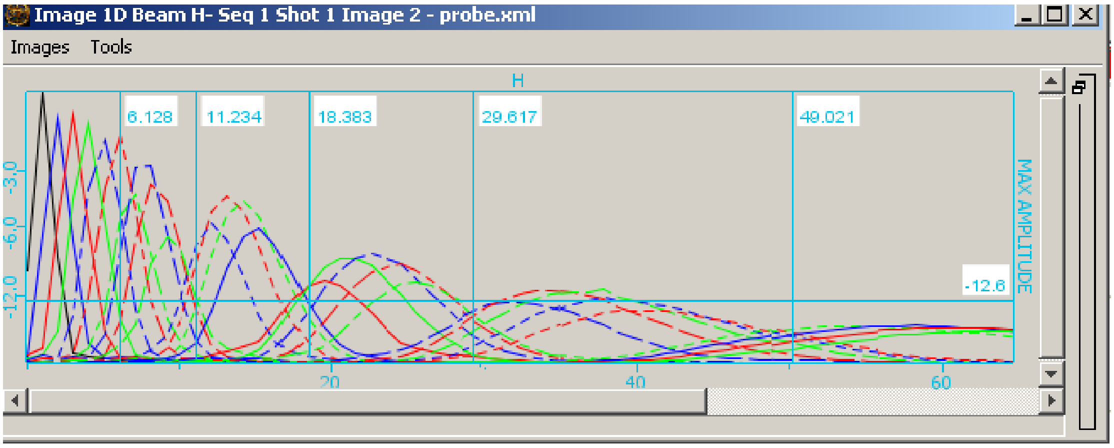
c. Transmitting pulse focused on 25mm, received pulse dynamic focusing, step 3, test range19-31mm.



d. Transmitting pulse focused on 40mm, received pulse dynamic focusing, step 4.5, test range 31-45mm.



e. Transmitting pulse focused on 65mm, received pulse dynamic focusing, step 7, test range 45-81mm.



f. Dynamic focusing curves synthesis

Fig.6 Development of dynamic focal laws

4.2 C-scan with phased array dynamic focusing comparing to multi-zone focused transducers

Adopting the focal laws above, the φ75×80mm super alloy sample was tested with C-Scan, divided to 7 zones — two single-point focal law used to test the depth under 10mm and 5 dynamic focusing laws shown in Fig.6 of other zones. One phased array transducer was used for the 7 zones in one scan. The results of 7 zones detected are presented in Fig.7 simultaneously. In the image the minimum defect detected with phased array dynamic focusing showed an amplitude of φ0.4-24dB. The signal-to-noise ratio is excellent to allow detection of small defects.

Phased array dynamic focusing permits optimizing the beam shape at the expected defect location, as well as optimizing probability of detection. At the same time, Focusing significantly improves signal-to-noise ratio.

The results of multi-zone inspection with some focused transducers of 10MHz frequency, shown in Fig.8, are compared to the C-Scan image in Fig.7 with phased array transducers. From the two figures, we can see the defects shown on the image of each zone of the disk with these two methods are basically the same.

The save on detection time is obviously shown with phases array dynamic focusing. The time for 7 scans of multi-zone inspection is 7 times longer than one scan of the disk inspection with phased array dynamic focusing. At the same time a lot of time for transducer adjustment is saved with the phased array method.

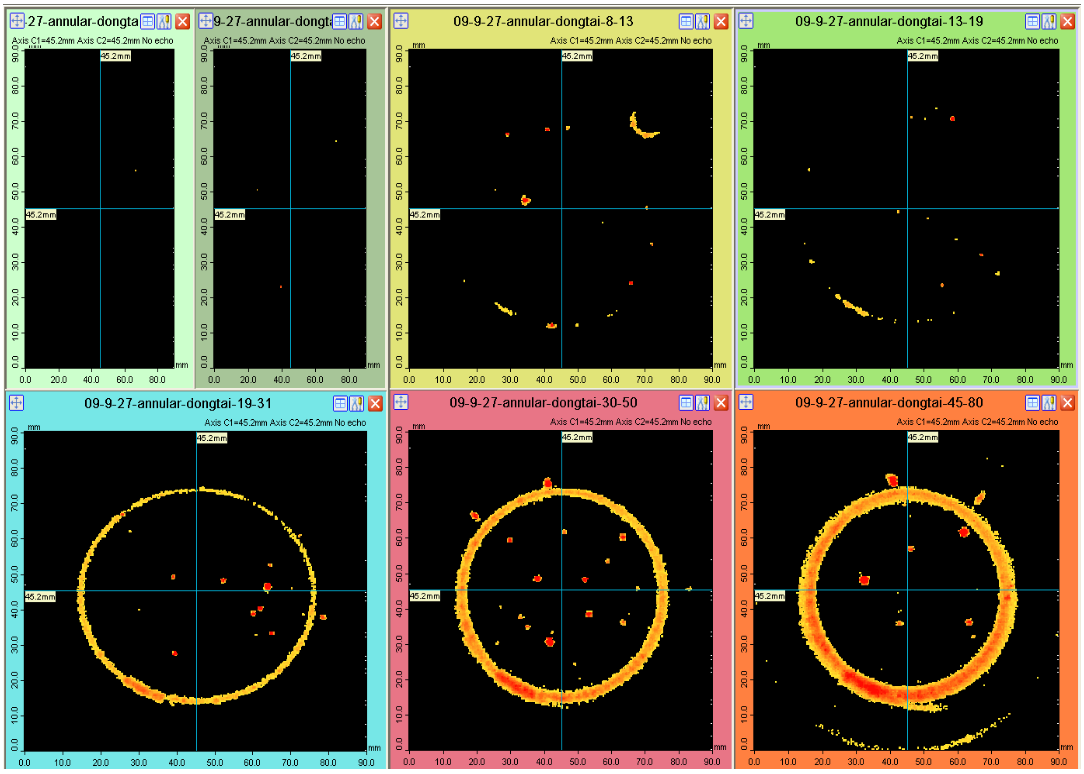


Fig.7 C-Scan images of phased array dynamic focusing inspection of the sample

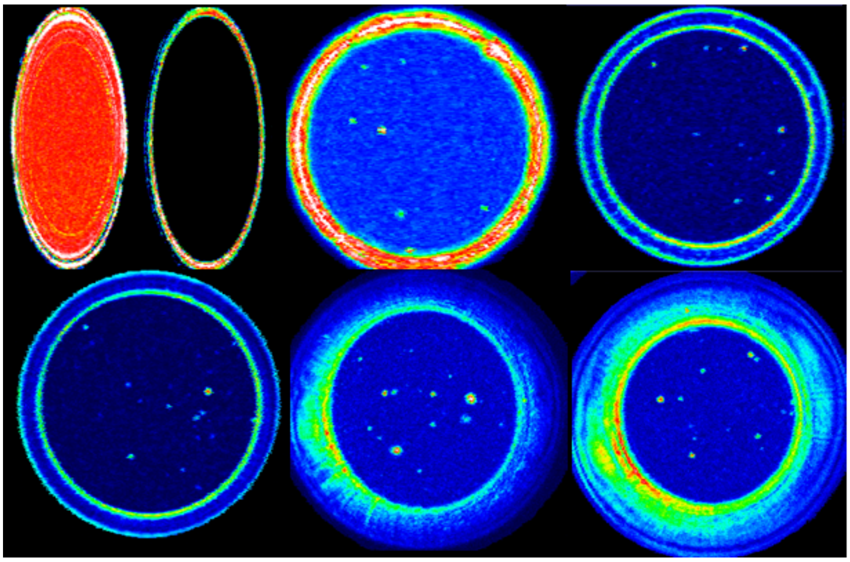


Fig.8 C-Scan images of multi-zone inspection of the sample with focused transducers

5. Conclusion

Sound field simulation and calculation method is very useful for the design of the focal laws of phased array testing. Phased array dynamic focusing can help to achieve high sensitivity and good signal-to-noise ratio in the whole thickness of the thick part.

Compared to the multi-zone focusing technique with conventional transducers, phased array dynamic focusing can give not only the same inspection ability of small defects, but also a saving of inspection time enormously with only one scan of simply one transducer.

References

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Acknowledgements

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