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Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 249-250
3-5 December, 2014

Research of Array Inspecting on Structure with Dual-layered and Concave Interface by Total Focusing Method

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Abstract: In recent years post-processing of full matrix data using ultrasonic array has shown greater advantage in defect imaging and sizing than traditional phased array method. However its application on structure with dual-layered and concave interface has not been discussed about. This paper first discusses about the problem original TFM faced in concave structure inspection. The solution to correction is then given. At last experimental results show that the suggested TFM with sub-aperture is applicable for concave structure inspection. Original TFM can't be used directly in this case.

1. Introduction

Structures with complex geometry are widely used at this time of day. They play important roles through life time. For example, in aerospace parts like spars, strings, and top-hat structures consist of corners with small radius (≤ 10mm) as shown in **Fig. 1.** These concave structures are subject to a range of extreme operation conditions. Defects due to these effects can cause structural degradation and failure[1]. As a result, nondestrutive testing and evaluation of them become much more essential.

Fig. 1 Concave structure in aerospace

Recently post-processing of full matrix data of linear array has been proven to have better accuracy in defect imaging and sizing (like Total Focusing Method - TFM) than traditional linear phased array approach[2-4]. But the array transducer is coupled directly onto testing pieces without wedge or water in most of the work. Only a few papers discuss TFM in dual-layered situation when parts has a convex interface by the help of Fermat's Principle[5]. As the author we doubt whether TFM can be used in concave structure like the convex case for several reason. Firstly some researchers have pointed out that there exists more than one stationary points satisfied Fermat's Principle when wave transmits to a certain point through a conve interface[6]. Secondly reflection signals by interface itself may be too complex to analyze.

So in this paper the correction of TFM will be implemented to allow post-processing method applicable to inspecting structure with dual-layered and the concave interface. Experimental results show that the correction of TFM has good accurancy in defect imaging of concave structure. On the other hand, the background signal from concave interface makes the orignal TFM unable to distinguish defect.

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2. Theory

2.1 Full matrix data and the total focusing method

Full matrix data is a data set of time domain signals for every possible transmitter-receiver combination in an array transducer. The advantage of full matrix data is that any A-Scan data received by steering beam in traditional phased array method can be obtained by a certain post-processing algorithm[7].

Total Focusing Method (TFM) is one of the most useful post-processing algorithm for image reconstruction from full matrix data. It has been termed the 'gold standard' for array processing. In TFM the beam is focused at every point in the image region. The algorithm proceeds by first discretizing the image region into a grid (in the x-z plane). The signals from all the elements in the array are then summed to synthesise a focus at every point in the grid. The intensity of the image, I(x, z) at any point in the scan is given by:

$$I(x,z) = \sum \left| m_{tx,rx}(T_{tx,rx}(x,z)) \right| \quad (1)$$

where *tx*, *rx* stand for elements on array used for transmitter and receiver respectively. $m_{tx,rx}$ is the full matrix data. $T_{tx,rx}(x,z)$ is the time-flight of ultrasonic reflected signal from *tx* to *rx* assuming an defect at location (x,z).

2.2 Calculation of time-flight through dual media with concave interface

For the purpose of imaging concave structure using Eq. (1), the algorithm to calculate time-flight through dual media with concave interface is required to correct. To avoid the multi-stationary point problem caused by Fermat's Principle a new numerical algorithm based on Snell's Law is suggested.

2.3 Image Algorithm

Considering the effect of reflection signal from concave interface, TFM image of concave structure may suffer from strong noise. It has a bad influence on defect imaging and sizing.

To avoid these effects we make another correction of TFM by by just sub-aperture of elements on array transducer for TFM. The sub-aperture depends on the point to be focused. And the line connected the center of the subset and focused point is normal to the curve of interface as shown. The TFM with subs-aperture will be used in following experiment.

3. Experiment Configuration

An experiment to inspect corner structure of aluminum is conduct to validate the image algorithm. The radius of couple interface is 5mm. The structure is embedded with circle void defect at 30° respected to the center of concave surface as shown in **Fig. 2**. An experiment system for full matrix capture and post-processing has been designed. After full matrix data is collected traditional TFM and TFM with subset aperture were used to image the structure respectively.

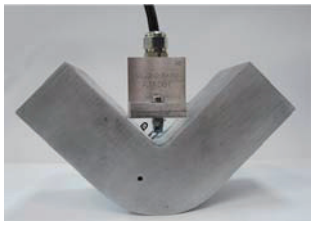
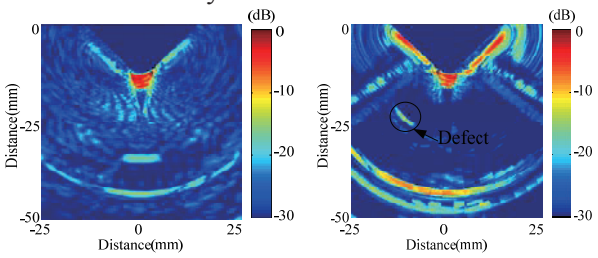


Fig. 2 Aluminum concave structure

4. Result and Discussion

The images ware rendered at a solution of 0.2mm per pixel. From the TFM result shown in **Fig. 3(a)**, as the discussion above the defect is totally covered by interface reflection and noise signal. While in the image of TFM with sub-aperture as shown in **Fig. 3(b)** the defect can be seen clearly. The amplitude of the reflection from defect is about -10dB. The amplitude of backgroud is about -9dB. The angle of defect calculated from the image is 28.3°. It means that the error of location accurancy is below 6%.



(a) **(b)**

Fig. 3 Imaging result (a)TFM, (b)TFM with sub-aperture

5. Conclusion

An application of inspecting structure with dual-layered and concave interface by total focusing method is presented in this paper. Two correction of original TFM are made. First, the algorithm for calculation of time-flight in concave structure is built by Snell's Law. Second, sub-aperture is recommended to avoid unwanted reflection signal from interface. The experiment result shows that the original TFM can't be used for concave structure inspection directly. However TFM with sub-aperture can image defect in concave structure directly and has a good accurancy.

The limitation of the algorithm is the time to calculate focal law for TFM imaging. Further work should be done to optimize the algorithm.

Acknowledgement

This work was supported by The National Natural Science Foundation of China (NSFC) (No. 51375027).

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