Signal Processing Approach for Defect Classification Detected Using Ultrasonic Phased Array

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Abstract
During the inspection, it is very important to know parameters and type of defect. Main types of defects are volumetric, which are not stress concentrators and therefore they can’t grow, and fatigue cracks, which can cause failure. Among all the methods of inspection, ultrasonic testing is a widely used method. Traditional ultrasonic testing with monolithic piezoelectric transducer can only focus in a fixed location. To achieve inspecting through all the depth direction of controlled object, different transducers having different focal lengths are required. Obviously, the testing efficiency and velocity are low. To overcome these difficulties, a possible solution is the application of Ultrasonic Phased Array (UPA) techniques. The possibility of applying ultrasonic phased array method for developing automated classifier of detected defects is the main aim of the research.

Keywords: Defect classification, ultrasonic inspection, signal processing, phased array

1. Introduction

Ultrasonic methodologies are the most practically feasible NDT applications in the area of material characterization. Ultrasonic testing is used extensively throughout the industry for quality assessment and detection of defects in engineering materials. The main aim of ultrasonic inspection of engineering materials is the detection, location and classification of internal flaws as quickly and accurately as possible [1]. Despite the advantages of ultrasonic technique, a high velocity of inspection, high probability of detection and low number of false results, the classification of defects based on ultrasonic signals is still frequently questioned. Normally the classification of the signal is carried out visually; and so this basically depends on the ability and knowledge of the operator. The progress in techniques has greatly increased the development of different systems for inspection and classification of defects.

Using the linear phased array approach the volume is scanned in much the same way as the conventional UT technique. However, it is not necessary to know the attachment geometry prior to performing the inspection and it is possible to scan all the volume on one side of the attachment at one time. With the help of modern technique and development of different processing technique it become more possible to solve current NDT problems.

However, the correct classification of the type of discontinuity would allow a faster and more precise decision to be made in terms of repairing the damage, reducing the risk of failures and consequently any temporary production loss or negative environmental impact.

2. Theoretical aspects

Ultrasonic method enable defects detection and estimation of their geometrical dimensions as well. As the result of ultrasonic inspection we receive signal (A-scan), with amplitude depends on piezoelectric transducer frequency, wave incident angle, depth and orientation of defect etc. In other hand, defects of different size and shape can have the same equivalent area and reflect echo-signals with the same amplitude [1, 2]. It is known that the shape form of defect is very determinative for evaluation of numerous structures, products etc. Ultrasonic phased array technology is one of the most promising methods, information content of which allows you to get all the necessary information about the detected defect.
There is therefore a need to develop special software for processing the results obtained in the monitoring process using mentioned technologies that will simplify and efficiently solve the problem of evaluation of the technical state of the metal.

In this paper we propose to use several methods for solving problem of automatic defects classification, using phased array probes.

3. Methods and results

Phased array transducers are multi-element transducers where each transducer can be controlled individually. By varying the timing of each element, the ultrasonic signal can be focused or steered. The main advantage of using a phased array transducer is the ability to electronically steer a beam without any mechanically moving components. This allows several areas to be inspected in a short amount of time [3].

Three methods that allow to determine location, crack height and crack angle at the same time [4,5].

2.1 Relative Arrival Time Technique (RATT)

The relative arrival time technique (RATT) is a sizing technique based on time-of-flight readings, not on amplitude echo dynamic. This technique is also called satellite pulse observation time technique (SPOT).

The RATT (see Figure 1) has the following features:

- The crack size is less than the beam spread (divergence).
- The evaluation is relative to the corner trap time-of-flight (TOF) signal.
- The crack corner trap and the crack tip are detected by the same angle at the same position of the probe.
- The relative ultrasound path between the crack corner trap and the crack tip signals is measured with AUT.
- The crack height is determined by:

\[
h_{\text{crack}} = \frac{\Delta U_{\text{RATT}}}{\cos \beta} = \frac{U_{T2} - U_{T1}}{\cos \beta}
\]

![Figure 1 RATT crack height evaluation based on relative measurement of ultrasound path between crack tip and crack corner trap signals](image)

If the ultrasound beam has enough divergence (a longer ultrasound path and higher refracted angles), then the tip of the crack is detected by the direct beam and by the skip beam (see Figure 2). The signals are phased-reversed for direct detection and in phase with the corner-trap signal for skip detection.
The height factor dependence on the refracted angle is presented in Figure 3. One can conclude that $\Delta UT$ decreases when the refracted angle is increased. The best separation is achieved for "steeper" refracted angles, such as 30° to 35°.

2.2 Absolute Arrival Time Technique (AATT)

The absolute arrival time technique (AATT), also called pulse arrival time technique
(PATT), has the following features (see Figure 4):

- Crack height possibly greater than the beam width.
- Probe movement and two angles required for optimum ultrasonic path reading.
- Reading corrected for angle and ultrasound path.
- The probe is scanned manually over the crack area to detect the root corner signal and maximize the crack tip signal.

![Crack height measurement principle using AATT](image)

**Figure 4** Crack height measurement principle using AATT

In phased array ultrasonics, the beam can sweep over the crack facets using an S-scan and the height is evaluated (see Figure 5). Similar approaches use electronic B-scans or raster scans.

![Example of AATT sizing of a fatigue crack with phased array probe in static position and beam sweeping over the crack](image)

**Figure 5** Example of AATT sizing of a fatigue crack with phased array probe in static position and beam sweeping over the crack: (a) principle; (b) sizing a 7 mm crack with the skip tip; (c) sizing a $H_{\text{crack}} = 10.2$ mm crack; $H_{\text{AATT}} = 9.9$ mm.
A reliable crack sizing capability based on tip-echo techniques depends on suitable specimen thickness, phased array probe frequency, damping, and bandwidth, as well as material quality.

Conclusions

Phased array applications do, however, offer more reliable and reproducible sizing than that obtained from manual A-scan ultrasonic applications, which is principally due to the following:
- Focused beams can be much narrower than conventional divergent beams resulting in higher precision during sizing.
- Phased array images compress numerous individual A-scans, allowing the NDT technician to observe all this data in one image.
- Coupling with arrays tends to be more consistent than when scanning with conventional probes.
- Collection of raw digital data in the form of phased array images allows offline sizing and software tools to be used to manipulate, merge, and filter data for enhanced evaluation.

The purpose of parameters determination is almost solved, one important factor in NDT – type of the defects still needs the new way of signal processing, but the main point of it is development of AATT for S-scans.

References