UTILISING PHASE RELATIONSHIPS FOR AUTOMATIC WELD FLAW CATEGORISATION IN TIME-OF-FLIGHT DIFFRACTION IMAGES

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ABSTRACT

Ultrasonic Time-Of-Flight Diffraction (TOFD) is a recent innovation that has proved highly effective for the inspection of steel plates and tubular pipelines and has started to take its way to replace the other ultrasonic testing techniques. It is anticipated that coupled with the necessary processing algorithms, TOFD can be used for a comprehensive automatic inspection of welds with satisfactory levels of accuracy and reliability. Although each defect category has unique characteristics and patterns but there are some similarities between these categories which make the discrimination between these categories not an easy task. Careful estimating the phase relations for each defect category is very important for providing an automatic interpretation system. The determination of the phase relationships between defect echoes and comparing them with the lateral wave and backwall echoes can be used for characterising defect classes and also to achieve accurate defect sizing. Therefore a phase determination system based on the measurement of correlation between the two signals has been developed. These phase determination results can be combined with artificial intelligent technologies such as fuzzy logic and neural networks in order to differentiate between different defect categories, thus opening a new paradigm in TOFD for automatic inspection.

1 INTRODUCTION

Ultrasonic techniques are still the most popular non-destructive testing methods applied to problems such as weld inspection. Currently most ultrasonic data interpretation is done manually, requiring operator skill, experience and most significant time. In light of the industrial pressure, the recent trend is to partially or fully automate the inspection and data interpretation process. This could potentially improve these procedures by adding an element of robustness and consistency by utilising computational tools that are better suited to discriminating between subtle variations in visual and spectral properties of the data. Furthermore, this could potentially save human life, money, effort and time (Zahran [1]).

Each defect category has its main characteristics and patterns which may be used for the classification of these categories. Phase relations between defect echoes and the main signals of the scan, which are lateral wave and backwall signals, are the most important clues for characterising each defect category and also to achieve accurate sizing which is the main advantage of TOFD technique. Therefore it is very important to study, notify and estimate the phase relations for each defect category carefully which may be helpful in providing a comprehensive automatic interpretation system.

A phase determination technique based on the calculation of correlation between the two signals has been developed in order to be used to decide whether the two signals are in-phase or out-of-phase. This algorithm can be an essential part of a comprehensive automatic interpretation system of TOFD data (Zahran [2]).

2 TOFD

TOFD first appeared in 1977 and started to take its way to replace the other ultrasonic testing techniques. This technique has a lot of advantages which make it the preferable technique in material testing (Erhard [3], Krutzen [4], Trimborn [5]). There are many successful examples for applying TOFD technique, which show that TOFD is a powerful testing tool which gives accurate sizing, and characterising of weld defects.

TOFD is based on measurement of the time of flight of the ultrasonic waves diffracted from the tips of discontinuities (defects). This is directly related to the true position and size of the defect instead of geometrical reflection from the interface of the discontinuities in traditional methods (Silk [6]). This technique uses two probes in a transmitter-receiver arrangement as shown in Fig. 1. When ultrasound is introduced into the material, each defect edge works as a point source of diffracted waves. The received signals can be visualized in an A-scan presentation or stacked together to give a 2-dimensional image called a B or D-scan representation as shown in Fig. 2.

The most important advantages of TOFD technique are that, TOFD defect detection does not depend on the defect orientation, in contrast to the other techniques, defect height can be exactly determined, depth sizing is very accurate with a high probability of detection up to 95%, and very low cost (Betti [7,8], Hecht [9], Webber [10]).

Taking into account a 180° phase shift between the crack tip signals, the crack depth (or height) is calculated from the time of flight of both crack tip echoes. In addition, the phase-shift can be used for classification proposes by considering the phase relations between the diffracted defect echoes and lateral wave and backwall signals. By changing the distance between the probes, the focusing depth of the ultrasonic beams in the material (with maximum sensitivity) can be optimised for the locations where defects are expected.

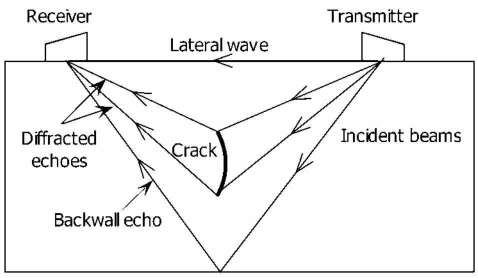

Figure 1: TOFD technique principle

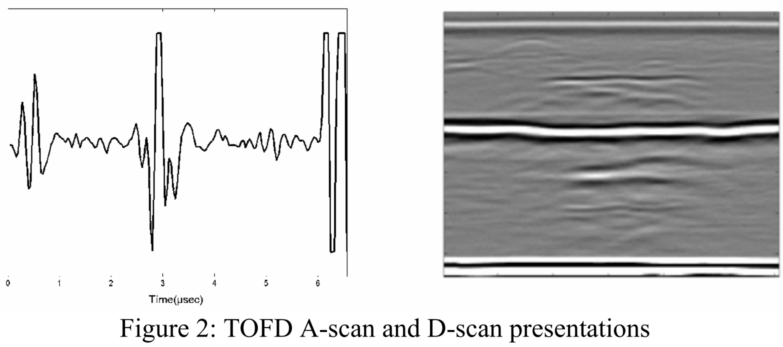

Figure 2: TOFD A-scan and D-scan presentations

3 PHASE RELATIONS

When a wave is reflected at the interface between two media from higher to lower acoustic impedance, there will be a 180° phase difference. Therefore when the backwall signal is reflected at the interface between steel and air, there will be a phase difference of 180° between lateral wave and backwall echo.

When the material under test containing a defect, there will be a 180° phase difference between the signal from the top of the defect and the lateral wave as if it had undergone a reflection which means that the phase is similar to that of the backwall echo. The signal from the bottom of the defect is still in phase with the lateral wave which means there will be a 180° phase difference between the two defect echoes as shown in Fig. 3.

Theoretically if there is a 180° phase difference between two adjacent diffracted signals, this means they must have a continuous crack between them. Rarely the bottom diffraction signals will not have this phase change.

The phase relation between defects echoes and the lateral wave and backwall echoes are different between different defect categories as explained in the following section. Furthermore sizing can not be performed accurately without considering the phase change between defect echoes.

4 DEFECT CHARACTERISATION

The common defects in welds can be classified into four main categories, planar flaws, volumetric flaws, thread-like flaws and point flaws (British Standard [11]). Each category has special characteristics and patterns but there are some similarities between categories which makes the discrimination between these categories not an easy task. It is very important to study these characteristics and patterns carefully in order to provide an automatic interpretation system.

Planar flaws include cracks and lack of fusion. Planar flaws may be open to the upper surface, breaking the lower surface or internal. The planar flaws open to the upper surface show up as an echo from the bottom edge of the flaw with a higher frequency content usually accompanied by a loss or a weakening of the lateral wave signal and the phase is still as the lateral wave. This is often accompanied by the apparent migration of lateral wave echoes to greater depths as shown in Fig. 4.

Planar flaws breaking the lower surface on the other hand show up as an echo from the top edge usually accompanied by an increasing delay in and/or weakening of the backwall signal. The effect on the backwall depends on the depth of the crack. The phase of the echo is still the same as the backwall echo as shown in Fig. 5.

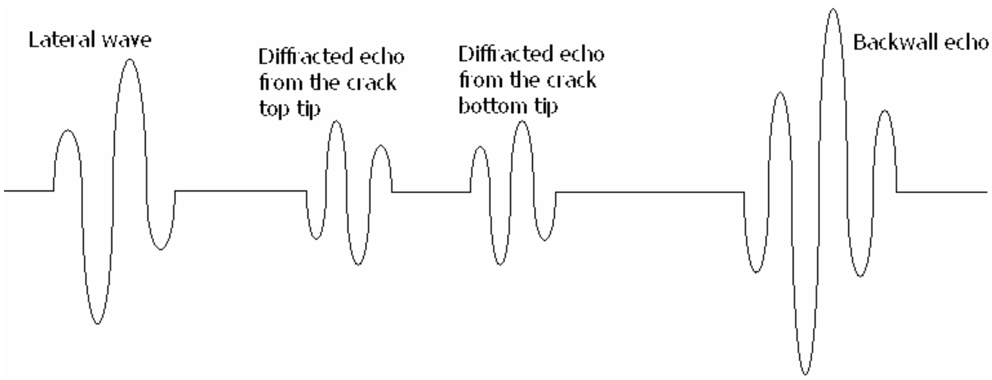

Figure 3: Phase relationships

Internal planar flaws show as two echoes with a distinct 180° phase difference between the echoes from the top and bottom tips of the flaw. The phase of the upper tip echo is the same as the backwall echo while the lower one is the same as lateral wave. Both echoes have a similar amplitude and defect signature as shown in Fig. 6. Lack of fusion is very similar to the internal cracks and both have two echo signals with 180° phase change.

Volumetric flaws include lack of penetration and large slag lines. The echoes from reflectors of this type also show the features and phases outlined for internal planar flaws but the echo from the upper surface is greater than the diffracted around the lower surface as shown in Fig. 7.

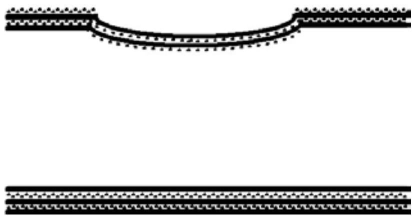

Figure (4): Upper surface breaking pattern

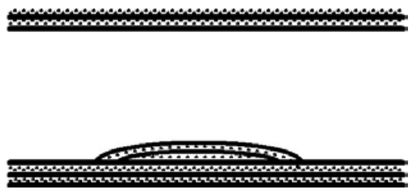

Figure (5) Lower surface breaking defect

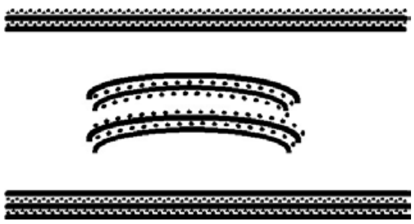

Figure (6): Internal crack pattern

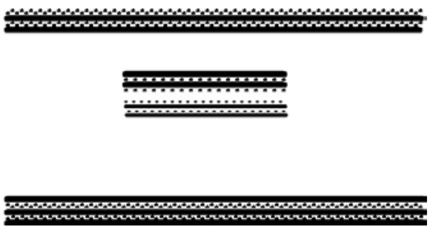

Figure (7): Large slag line

Thread-like flaws include flaws with significant length but little through wall extent such as lamellar flaws and near horizontal area lack of fusion. The reflector appears as an apparent upper edge echo in phase with the backwall echo without lower edge echo. The long narrow slag shown in Fig. 8 can be considered as an example of this category.

Point flaws include pores and small pieces of slag. These flaws are most common in welds and their echoes have similar pulse characteristics to the volumetric or thread like flaws but have no resolvable length. Point flaws give multiple echoes but with no other co-linear echoes at greater or lesser depth in the specimen which are similar to patterns of acoustic noise. The defects of this category produce signals which look like arcs on D-scan as shown in Fig. 9.

5 PHASE DETERMINATION

As shown above, the phase relations have to be considered for any discrimination between these categories. Therefore a phase determination algorithm has been developed in order to be used to decide whether the two signals are in-phase or out-of-phase.

This algorithm based on the measurement of the cross-correlation coefficient which indicates the degree of matching between the two signals. Depending on the value of cross-correlation coefficient, the decision is made.

This algorithm is applied only on the signals in the detected areas after applying automatic defect detection (Zahran [12, 13]). The results of this phase estimation algorithm can be used as a part of an automatic interpretation system.

6 CONCLUSION

The phase relations between diffracted echoes from the defect tips and also with the lateral wave and backwall signals have to be considered for any discrimination between different defect categories. A phase determination algorithm has been introduced as an essential part of a comprehensive automatic interpretation system of TOFD data. This can be done by combining the phase relations and the main characteristics of each defect category with advanced signal and image processing techniques to build an artificial intelligence system, which could greatly reduce the degree of reliance on the trained operator during initial site investigations.

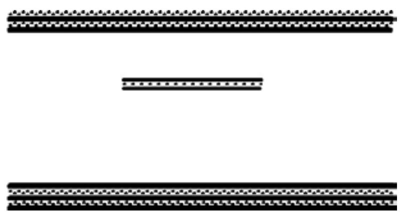

Figure (8): Threadlike flaw

Figure (9): Point flaws

7 ACKNOWLEDGMENTS

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