Time of Flight Diffraction - An Alternate Non-Destructive Testing Procedure to Replace Traditional Methods

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ABSTRACT

Time-of-flight-diffraction Technique (TOFD) is considered as one of the fastest methods of Non-destructive testing (NDT) since a weld can be characterized to a certain degree with one single scan along its length with two probes. An image of the complete weld is created showing component and, more importantly, any defect information. In this paper a comprehensive review of the TOFD technique covering many aspects, e.g. accuracy, coverage, resolution, repeatability, and last not least speed where the real value of TOFD lies-despite its few inherent limitations is presented. This paper presents the results of experimental investigations carried out using various NDT techniques including TOFD on specimens such as welds with various types of defects. The results of these investigations are compared and the feasibility of using TOFD as an alternative NDT procedure to replace the traditional NDT methods of inspecting fabricated pressure vessel components are examined.

Keywords: Time-of-Flight, Diffraction(TOFD), Non-Destructive Testing (NDT), resolution, accuracy, ultrasonic testing, defect characterization, D-scan, creeping wave, critical sizing, probability of detection.

1. INTRODUCTION

The major aim of Non-Destructive Examination of engineering structures and systems is assurance of integrity by confirming lack of defects in both the construction process and during the service life of the component. Major methods used for the non-destructive examination of welded components are radiographic testing, magnetic particle testing, liquid penetrant testing and ultrasonic testing.

The developments in automated inspection technology and the growth of Fitness For Purpose (FFP) inspection have propelled emerging techniques such as the Ultrasonic

Time of Flight Diffraction (TOFD) to the forefront of industry(1,2) . The TOFD technique is a fully computerized system able to scan, store, and evaluate indications in terms of height, length, and position with a grade of accuracy never achieved by other ultrasonic techniques. These features have extended the use of TOFD to replace Radiography and complex Ultrasonic inspection by a tandem technique wherever planar defects (cracks, lack of fusion) are the main object of examination Like any other technique, TOFD has its limitations. In general the technique is less suitable for coarse grained materials, such as many types of austenitic stainless steel. In addition, inspection reliability close to the scanning surface is hampered by the presence of the lateral wave, which may obscure anomalies present in this area.

This paper presents the results of experimental investigations carried out using various NDT techniques including TOFD on welded test specimens with defects. The results of these investigations are compared and the feasibility of using TOFD as an alternative NDT procedure to replace the traditional NDT methods of inspecting fabricated pressure vessel components are examined. The advantages and limitations of TOFD is outlined and the process compared with conventional pulse echo ultrasonic and radiographic inspection.

2. BASIC PRINCIPLES OF TIME-OF-FLIGHT DIFFRACTION TECHNIQUE (TOFD)

Rather than monitoring the (high) amplitude response of reflected energy and using this to make a comparative assessment of 'equivalent' defect size, TOFD relies on the detection of relatively low amplitude signals diffracted only from the tips of defects which forms a basis for absolute position (and therefore size) measurement - irrespective of amplitude response (3). Typical pattern of waves involved in TOFD technique and TOFD Images obtained during the scanning of a butt weld are shown in Fig. 1 and 2

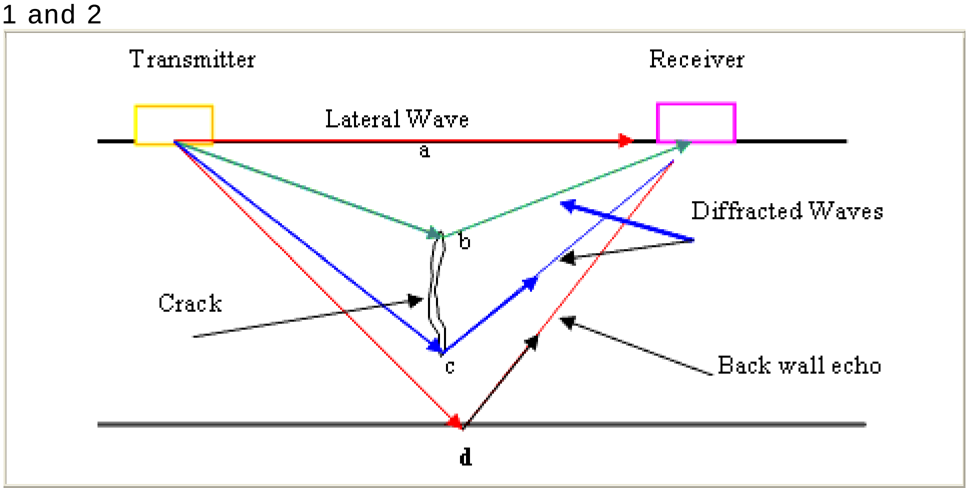

Figure 1 Typical pattern of waves involved in TOFD technique.

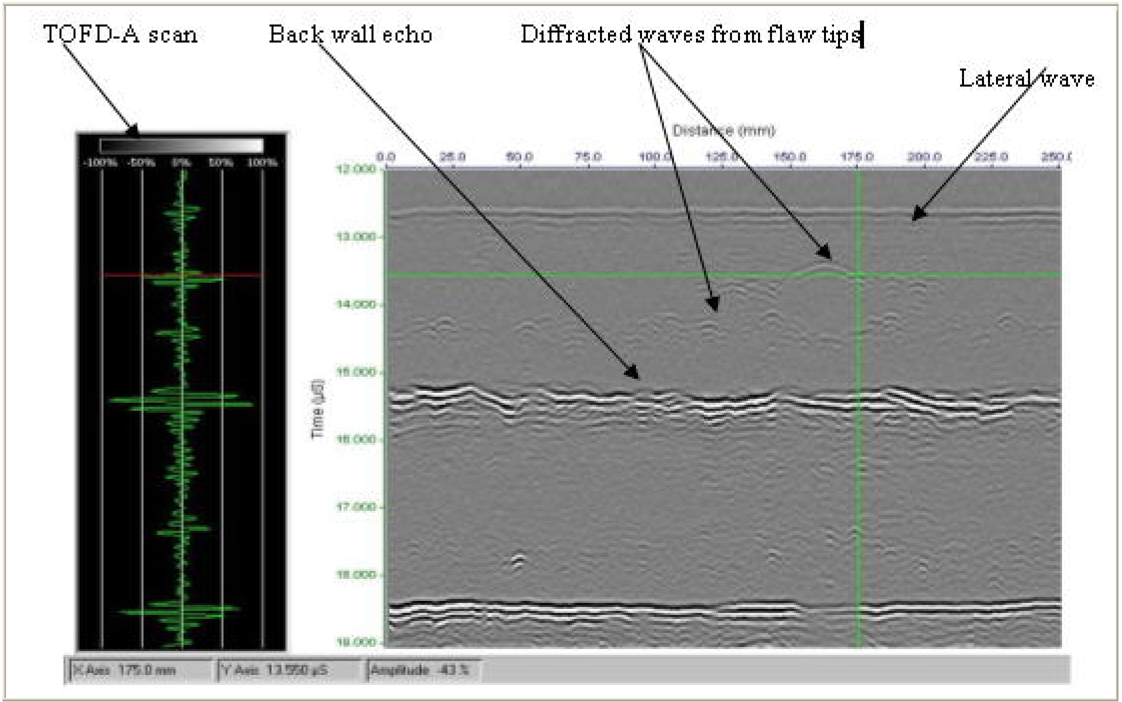

Figure 2 Typical TOFD Images obtained during scanning of a butt weld and corresponding A-scan image.

This is achieved by using two separate transducers in a directly opposed tandem configuration - both being reasonably well matched short pulse, wide beam probes of the same angle but one acting as transmitter and the other as a discreet receiver. As with conventional ultrasonic testing the majority of transmitted energy is lost through absorption and diffusion by the material under test or it is reflected by any discontinuities falling within its effective envelope - but some is radiated by these discontinuities and it is these very low amplitude diffracted signals on which TOFD relies. By capturing these responses and processing them in a fashion whereby they can be discriminated from background and structural noise it is possible to create an image which, by differentiation, makes it possible to identify the presence and location of defects and to accurately position these with respect to the geometry of the item under test(4,5).

Because the technique does not rely on detection of reflected energy it is not amplitude dependant (for defect size measurement) and therefore not so susceptible as 'pulse echo' testing to consistent surface and consequently couplant conditions. Also, because of the comprehensive coverage afforded by the characteristically wide probe beams used for TOFD the technique is not as dependant as conventional pulse echo ultrasonic to variances in probe position or defect orientation relative to nominal probe angle. This makes TOFD much less subjective in application and more effective as a routine detection method.

A typical pattern of indications (A-scan) is shown in figure 3. The height of the imperfection can be deduced from the difference in time-of-flight of the two diffracted signals. Note the phase reversal between the lateral wave and the back wall echo, and between echoes of the upper and lower tip of the imperfection(6,7).

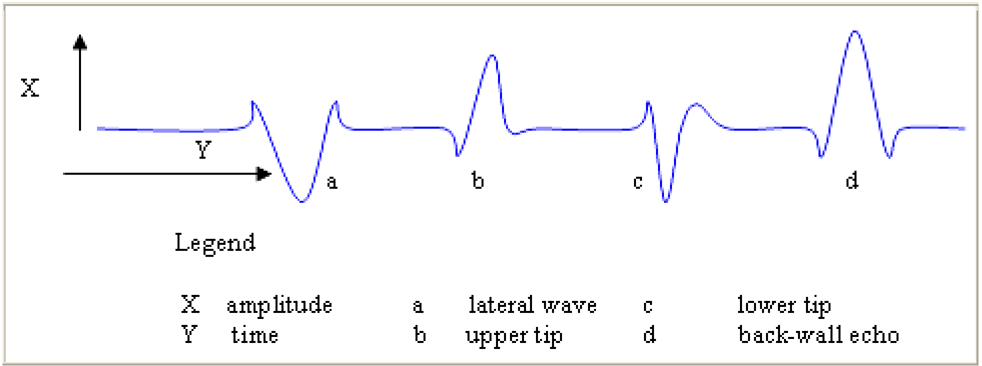

Figure 3 Schematic of TOFD A-Scan

3. EXPERIMENTAL INVESTIGATION

3.1 Scope

The following paragraphs detail the results of experimental investigations carried out on welded test specimens using various NDT techniques such as radiography, ultrasonic testing , magnetic particle testing , Liquid Penetrant Testing and time-of-flight diffraction technique (TOFD). The results of these experimental investigations are compared and the feasibility of using TOFD as an alternate NDT procedure to replace the traditional NDT methods of inspecting fabricated pressure vessel components are examined.

3.2 Equipment used for TOFD

TOFD equipment model MICROPLUS of M/S AEA Technology , U.K with manual scanner along with longitudinal wave angle beam probes of 45° (MHz) , 60° (MHz) and 70° (MHz) were used for the experiment.

3.3 Weld Specimens used for the experimental investigation

The details of the specimen used for the experimental study are tabulated in table 1. The first six specimens are manufactured from carbon steel plates and the 7th specimen (HITECH-S2) from austenitic stainless steel pipe. All the specimen listed in table 1 contained real flaws artificially induced .

Sl. No	Specimen Identification	Length X Width X Thickness (in mm)	Material	Defect Type
1	WIS S1 D1	150 x 75 x 10	Carbon Steel	Toe Crack
2	WIS S1 D5	150 x 75 x 10	Carbon Steel	Centre line Crack
3	WIS S3 D7	150 x 75 x 10	Carbon Steel	Slag Inclusion
4	UTC-S1	350 x 250 x 20	Carbon Steel	Slag
5	UTC-S2	350 x 250 x 25	Carbon Steel	Clustered pores & Slag
6	HITECH-S1	350 x 250 x 15	Carbon Steel	Clustered pores & Slag

7	HITECH-S2	300 x 200 x 30	Austenitic SS	No defect

Table 1 Test Specimen details

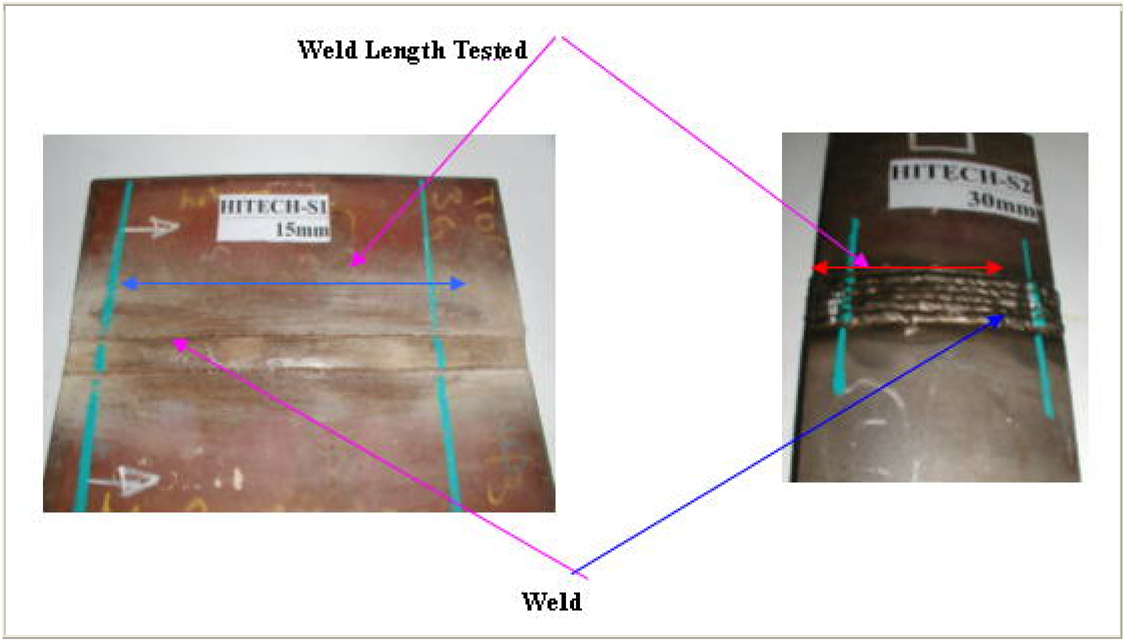

Figure 4 Test Specimens, HITECH-S1 and HITECH-S2 used for the experimental study

3.5 Results of TOFD Measurements

Sl. No	Specimen	Flaw Lengths	Flaw depth (From top surface)
1	WIS S1 D1	23.0mm	5.8mm
2	WIS S1 D5	23.0mm	8.0mm
3	WIS S3 D7	26.1mm	6.3mm
4	UTC-S1	12.0 mm , 40.0mm	7.7mm, 8.4mm
5	UTC-S2	62.0mm	7.4mm
6	HITECH S1	48.0 mm, 51.0mm	6.5mm, Surface breaking crack s (depth up to 6.0mm)
7	HITECH S2		No recordable indications

Table 2 Results of TOFD Measurements

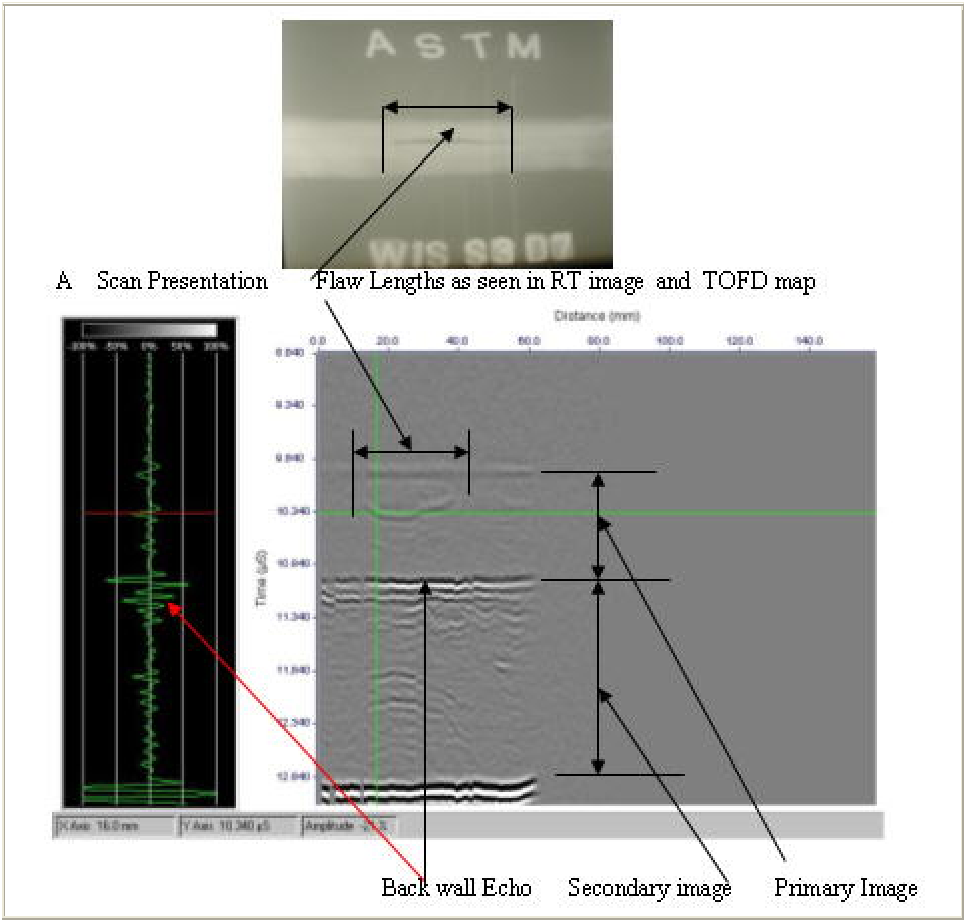

Figure 5 Flaw Length as seen in TOFD map and RT image

3.6 Comparison of Experimental Results

Test Specimen	UT Results Length in mm	RT Results Length in mm	MPT Results Length in mm	TOFD Results Length in mm
WIS S1 D1	25.0	25.0	NRI *	23.0
WIS S1 D5	25.0	24.0	NRI *	23.0
WIS S3 D7	25.0	26.0	NRI *	26.1
UTC-S1	15.0, 35.0	12, 41.0	NRI *	12.0 , 40.0
UTC-S2	67.0	65.0	NRI *	62.0
HITECH S1	50.0, 46.0	49.0, 50.0	Surface Cracks	48.0 , 51.0
HITECH S2	----	NRI*	------	NRI*

Table 3 Comparison of Experimental Results
* NRI - No Recordable Indications

4. RESULTS AND DISCUSSION

The experimental investigations described above demonstrate that the TOFD technique is a new powerful tool to improve the results of NDE examination of welds. TOFD technique is able to detect defects which are normally visible either by radiographic examination or traditional ultrasonic testing (pulse echo). Images obtained by TOFD guarantee that the examination is reliable and complete in terms of coverage of the zone to be inspected. They also illustrate the overall quality of welds in a compact and rational form. Reviewing the multitude of TOFD images and comparing with A-scan presentation from pulse echo technique and Radiographic images it appears with great evidence the richness of TOFD images. The number of information obtainable simultaneously observing a TOFD image give us an image of the flaws close to the reality.

TOFD procedure could detect 100% of the specimen defects detected by radiography and pulse echo ultrasonic. TOFD has high sensitivity in detecting planar, vertical or oriented defects like cracks or lack of fusion not visible by radiography and hardly detected by standard ultrasonic pulse echo technique. Based on the experimental investigations and the comparison of test results the it can be concluded that TOFD can be used as an alternate NDT procedure to replace the traditional NDT methods of inspecting fabricated pressure vessel components.

REFERENCES

1. J.P. Charlesworth, J.A.G Temple " Engineering Applications of Ultrasonic Time-of -Flight Diffraction" Research Studies Press Ltd, England
2. J.A.G. Temple , " Time of flight Inspection Theory", Nuclear Energy, Oct. 1983, 22, No.05, pp.335-348
3. M.G. Silk. "The use of diffraction based Time of Flight measurements to locate and size defects", British Journal of NDT, May 1984.
4. Bill Browne "Time of Flight Diffraction-Its Limitations-Actual and Perceived" NDTnet-Spet.1997, Vol.2, No.09 www.ndt.net/v02n09.htm.
5. M.G Silk, B.H.Linditngton, " The potential of scattered or diffracted ultrasound in the determination of crack depth", NDT journal, June 1975, pp-146
6. British Standard BS 7706: 1993 " Guide to calibration and setting-up of the Ultrasonic Time-of-Flight-Diffraction(TOFD) technique for the detection, location and sizing of flaws".
7. European Pre-standard ENV 583-6 " Non-destructive testing-Ultrasonic examination-Part 6: Time-of-Flight-Diffraction Technique as a method for detection and sizing of discontinuities".