The Application of TOFD Technique on the Large Pressure Vessel

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Abstract

The TOFD technique (Time of flight diffraction) is an ultrasonic image-generating technique, which offers the capability of detection, location and sizing. To a certain extent characterization of discontinuity in the weld material as well as in the adjacent parent material is also possible. Compared with purely reflection-based techniques, the TOFD technique, which is based on diffraction, is less sensitive to the orientation of the discontinuity. Simultaneously, the determination of the defects relies on the time of flight diffraction rather than the amplitude of reflection wave as the conventional UT method. So, the detectable reliability of the discontinuity is much enhanced.

Presently, the TOFD technique is widely used to the metal NDT on the nuclear industry, the power industry and the pressure equipments. This paper describes the using of the TOFD equipment which is made by the AIS company in America. In the field, we performed the three inspections on a large spherical vessel ($3000M^3$) using the TOFD and X-ray radiography and conventional UT independently. Compared the testing results, we can conclude that the TOFD technique not only has the higher detectable probability of defects, but also has the higher measuring precision on the height of defects than RT and UT.

Keywords: TOFD, Diffraction, Pressure Vessel

1. Foreword

There are many numbers of spherical vessels which are widely available for material storage in petrochemical industry. Because storing material in the spherical vessels almost is flammable, explosive and nocuous gas or liquid as well as liquefacient gas, once an accident occurs due to defects in the spherical vessels, the catastrophe will be brought. So, periodical inspection is an important means ensuring spherical vessel security besides of design, manufacture and building in as well as operation on the vessels.

In the inspection of the spherical vessel, usual nondestructive testing methods are RT, UT, MT, AE, etc. Recently, several new methods such as TOFD technique, Magnetic Memory Testing are increasingly used in the periodical inspection of special equipments. For comparing testing results of several ways, the RT, UT, and TOFD are applied to the No.601 sphere in the Guangzhou Petrochemical Company Limited. This spherical vessel has served almost 6 years with the contents of liquefacient propylene. The basic information is

summarized in table 1.

Table 1 The information of the sphere

No.	material	thickness	volume	diameter	welding means	root shape
601	IE537-2	50mm	3000M^3	17.9M	manual arc	unsymmetrical “X”

2. RT and UT application

According to the requirement of《Periodical Inspection Rule For The Pressure Vessel》,we have performed the information audit, inside and outside surface examination and MT on the inside surface of the sphere in turn. Afterward, we have carried out RT to the sphere weld with 20% scale including but not limited “T” form weld. Along the more than 400 radiographs, 12 unqualified defects in the 12 radiographs were found including 8 slags, 3 lack of fusions and 1 crack. And then, the UT is applied to these defects in order to confirm the results of RT on the outside surface. In 12 flaws, 10 defects were found. The missing 2 flaws is slags. Finally, the TOFD technique has been performed to two defects (a crack and a lack of fusion) among all these defects and is described in detail as follows.

3. Principle of TOFD Technique

The TOFD technique is based on measurement of the time-of-flight of the ultrasonic waves diffracted from the top and bottom tips of a defect or discontinuity when a longitudinal wave is incident on it . The most significant distinction between TOFD and the other UT methods is that it monitors only diffracted echoes from the tips of defects rather than reflected ultrasonic echoes[1].Two wide beam angle probes are used in transmitter- receiver mode. Broad beam probes are used so that the entire inspected area is flooded with ultrasound, consequently, the entire volume is inspected using a single scan pass along the weld line.

In this technique, one transducer acts as transmitter and the other as receiver and maintains a fixed distance. In addition to energies diffracted by defects, the TOFD method will also detect a lateral wave propagating directly between the probes and also a back wall echoes from energies that reach the back of the test piece without interference from defects[2].The difference in the flight of the diffracted wave fronts carries the information on the spatial relationship of the tips of the defect and hence the extent of the defect . The TOFD method only evaluates diffracted echoes, which are 20dB less than the reflected echoes[3]. Gray scale or color difference imaging technique is applied to the RF signal phases and enable weld integrity to be observed in real time. The principle of TOFD technique is demonstrated in figure 1.

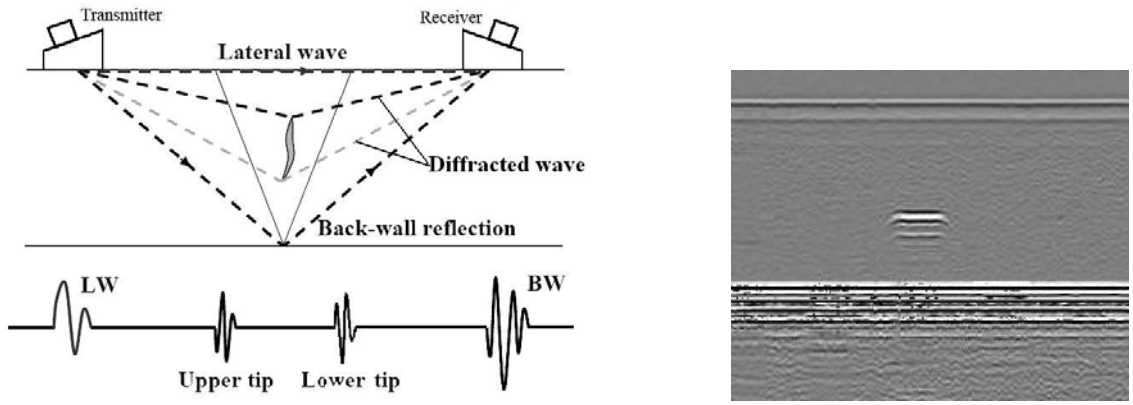


Figure 1 Principle of TOFD technique (left is A-scan; right is TOFD image)

Diffracted waves from the defect tips spread over a wide angular range, they can be easily detected, with little regard to defect orientation. Diffracted waves from the top and bottom tips of a discontinuity have different phases they are able to differentiate closely spaced flaws, and their spatial separation is directly related to the height of the discontinuity. Because the technique relies on detection of the forward scattered diffracted signals originating at the flaw tips, precise measurement of flaw size, location, and orientation become highly realistic[4].

4. Application of TOFD

4.1 The testing instrument

The TOFD instrument is portable NB-2000 Multi-Channel TOFD system developed by AIS company in the USA. The performance parameter is below:

- Up to 16 Channels, 120 MHz A/D
- 32 Transducer Cables Built in hardware/software to control automated scanners
- Dual axis magnetic wheel automated scanner
- Controller built into motor, inherently requires short power leads

4.2 Transducers layout and calibration

According to the standard《CEN/TS 14751 : TOFD on Weld Seams 》(September 2006 edition) 8.2 item, the thickness 50 just needs a pair of TOFD set-up. However, the dead zones are of in the top and bottom sections of weld, So, the creepers and PE probes were available to these zones inspection. So, three pairs of probes including a pair of 60º TOFD probes, a pair of creepers, a pair of 45º PE probes were applied to the weld inspection. These probes were distributed as figure 2 and the scanning frame was set up as figure 3. The parameters of these probes were tabulated in table 2.

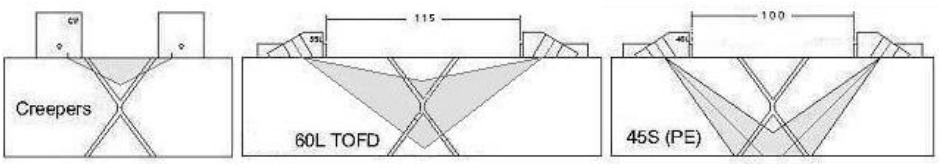


Figure 2 Probes distribution of TOFD scanning

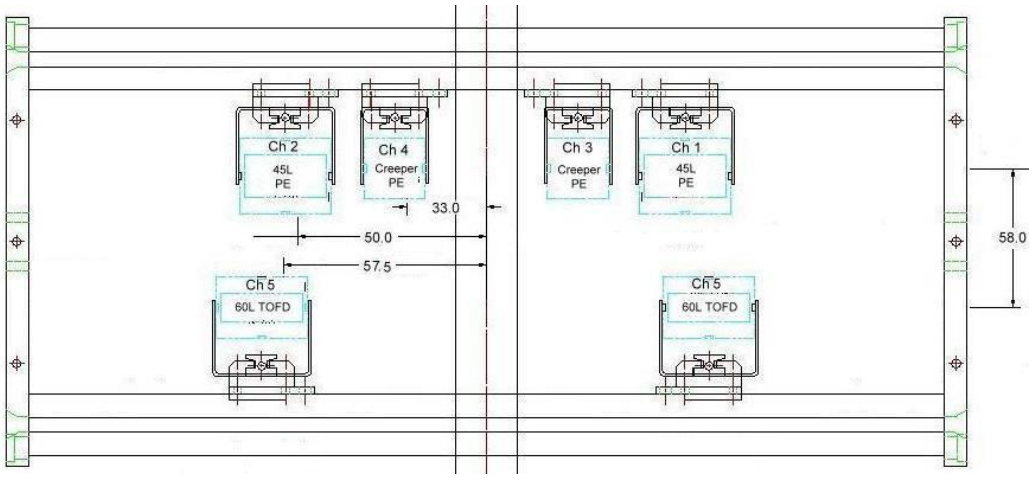


Figure 3 The set-up of scanning frame

Table 2 The probes parameters

Probe type	Centre-frequency	Beam-angle (long-waves)	Element-size	Probes center spacing
Creeper	2.25 MHz	90°	12.7mm	weld width(66mm)
TOFD	5.0 MHz	60°	5.0mm	115mm
PE	2.25 MHz	45°	12.7mm	100mm

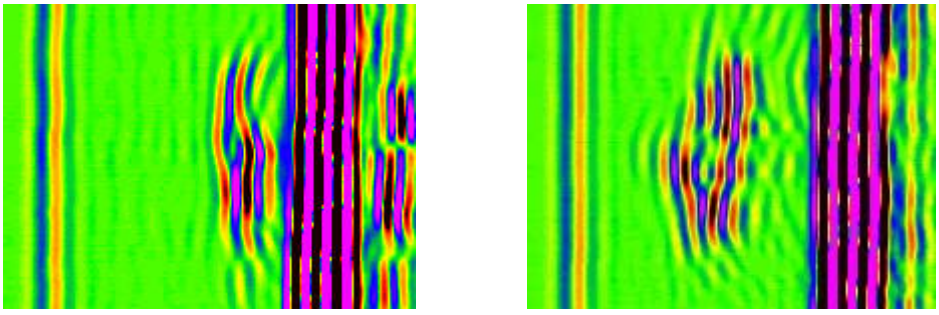
The prescribed Block with Similar Weld Geometry to the inspected weld is applied to calibrated the system using the lateral waves and the back-wall reflection waves. Simultaneously set up the encode.

4.3 TOFD scanning

In the areas in which the crack and lack of fusion were detected, the track with 1.2m length was put down for scanner's automatic scanning. Before scanning, the probe frame should be centered weld in order that each pair of probes is symmetrical distributed in two sides of weld seam. Then, the system automatically scanned the weld after the power was turned on.

4.4 The defects evaluation

The two defects were evidently observed in the TOFD images demonstrated in figure 4.



(a) crack (b) lack of fusion

Figure 4 TOFD images of the defects

Detects testing results are summarized in table 3.

Table 3 Testing results of RT, UT and TOFD

inspection method	Defect 1				Defect 2			
	length	depth	type	height	length	depth	type	height
RT	12mm	/	crack	/	15mm	/	lack of fusion	/
UT	13.5mm	38.9mm	linear	/	14.5mm	18.5mm	linear	/
TOFD	12.8mm	38.1mm	planar	3.2mm	15.8mm	18.2mm	planar	4.6mm

It is clearly concluded:

(a) Reliability on TOFD testing defects is advanced remarkably. Since TOFD technique is based on the detection of diffracted signals, it is not affected by the orientation of the discontinuity and angle of examination.

(b) Discontinuity depth and height can be very accurately determined in TOFD inspection. The TOFD evaluates height and location of defect by measuring the time of flight of diffracted signals generated from the tips of defect rather than the amplitude of reflected signals from the defects.

(c) Rapid scanning is possible and weldments can be scanned in single pass making this technique more efficient and faster.

5. Conclusion

The TOFD technique is a rapid, versatile, reliable and an effective advanced UT based NDT method for inspection of welds especially for heavy walled pressure vessels (both pre-service and in-service) aimed at better flaw detection and accurate evaluation of flaw location and flaw sizing with real time weld integrity assessment and acquisition of data to be stored for future inspection reference. With the recognition from international bodies like ASME, BSI etc and national standard like imminently updated JB4730-2005, TOFD will gain much more importance across the globe and will be applied for weld inspection very widely in the future.

References

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