Time of Flight Diffraction (TOFD) High Precision Weld Inspection

Fundamentals of an advanced non-destructive technique for reliable flaw detection.

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TÜVRheinland®
Precisely Right.

Introduction

The high performance of Time of Flight Diffraction (TOFD) in regard to detecting weld defects has led to a rapidly increasing acceptance of the technique as a pre-service inspection tool.

Since the early 1990's, TOFD has been applied in several international round robin exercises, where it has been validated against the more traditional radiographic and pulse echo testing.

TOFD has demonstrated real time savings during construction and maintenance programs, and provides an excellent base line for future inspections.

International acceptance criteria, codes and standards now include the facility to use TOFD.

Advantages of the TÜV Rheinland Sonovation approach:

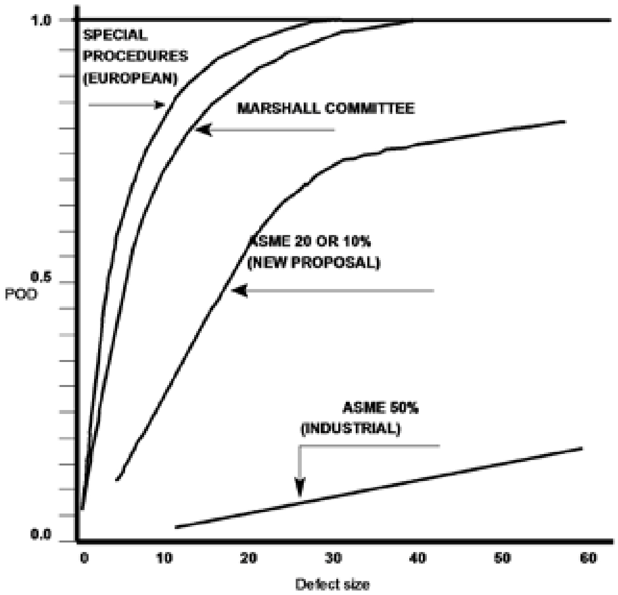
- Because no ionizing radiation is used, the inspection does not interfere with the production. process. TOFD inspections can, therefore, take place in parallel to production work.
- There is no need to transport pipe-spools, vessels or other parts to an X-Ray facility; eliminating the associated logistic problems and cost.
- Thickness variations do not greatly affect TOFD inspection speed, so very thick materials can be examined in a similar fast and efficient manner.
- TOFD examinations can be performed at temperatures in excess of 400ºC on finalized welds.
- Partly-welded thick sections can be examined at pre-heat temperatures to avoid costly root repairs from the outside surface after welding is complete.
- TOFD data is extremely accurate and presented in an easy-to-understand format. All data is stored for future reference and available to the client in a format compatible to that used in data bases for inspection and maintenance management. Differences in new-build situations after in-service periods can be easily identified, providing a good basis for lifetime and inspection interval extension programs.
- The ability to examine defects of different orientation combined with encoded positional data offers improvements in inspection reproducity.
- TÜV Rheinland TOFD pre-service inspections are based upon procedures developed according to the ISO 9001 quality system.
- All staff are trained in accordance with the "TÜV Rheinland Sonovation Written Practice", which conforms to ASNT SNT-TC-1a, ISO 9000 and where necessary to ASME XI ed. 1992 appendix 8 or ASME I and VIII, division 1&2 Code Case 2235.
- TÜV Rheinland Sonovation staff are certified in accordance with the TOFD certification program based upon ISO 9712 (former EN 473) involving independent examination.

References and Qualifications

TÜV Rheinland Sonovation is certified in accordance with the requirements of ISO 9001, by Lloyds Register of Quality Assurance and to VCA*, a health, safety and environment assurance and is one of the most experienced and best-resourced TOFD inspection companies in the world. After the 1971 development of TOFD by UKAEA Harwell and subsequent applications in the seventies, a large number of projects and round robin trials where undertaken by TÜV Rheinland Sonovation, AEA Technology and others, aimed at increasing the applicability and effectiveness of TOFD and validation of the techniques and procedures applied.

Some of these are:

- PISC trials (1977 - 1994, Nuclear applications)
- DTI MEMT requirement board trials on planar and non-planar welding defects (1980) proving the sizing capabilities of TOFD
- UKAEA DDT
- NIL NDO 1 project (1983-1986) 30-150 mm welds
- NIL NDO GF project (1990-1991) 10-38 mm welds
- Qualification for primary piping for TÜV Germany (1987)
- EPRI trials, vessel and nozzle samples (1989)
- TÜV Rheinland Sonovation is the first company in the world to achieve PDI qualification in accordance with ASME XI, edition 1992 appendix VII and VIII (1993)
- NIL thin plate project (1993 - 1995), TÜV Rheinland TOFD methodology qualified as fastest, most accurate and best in detection and false call rate on welds in plate thicknesses of 6-15 mm
- Lloyds approval for the application of TOFD (Lloyds report NDE/94/282)
- ASME Code case support trials (1995) on heavy wall vessel sample (350 mm)
- KINT Complex Geometry project (1995-1997) TÜV Rheinland proves reliability of nozzle inspections with TOFD
- KINT Acceptance Criteria Project (1997) Development of Good Workmanship Acceptance Criteria for TOFD with theoretical and practical verification
- TOFD PROOF project (2002-2005), Fifth Framework European Project, assessing the economic and technical benefits of TOFD compared to conventional methods through research and round robin tests, aimed at supporting European standardization



High performance of 'special procedures' compared with the average performance of ASME type procedures.

TOFD Experience

TÜV Rheinland Sonovation experience in using the TOFD technique stretches over a period of 25 years, in applications found in almost every type of industry. Project examples include pre- and in-service inspection in the Nuclear and Conventional Power, Defence and Oil and gas industries and chemical industries, and increasingly more inspections during fabrication welding over the last 10 years. Welds in large projects have been examined using TOFD as an alternative to conventional inspection techniques such as radiography in heavy wall vessels and high pressure piping.

Today, TOFD is acknowledged to be the most reliable method available for both detecting and sizing weld defects. The PISC program, a project that lasted many years, was used to establish the effectiveness of non-destructive testing techniques for the detection and sizing of defects in heavy wall pressure vessels. One of the PISC conclusions stated, “So called ‘special procedures’ that combine standard techniques and advanced techniques for sizing (but often also for detection, e.g. TOFD) obtain nearly perfect results”.

Advantages of the TÜV Rheinland Sonovation approach:

- In-service inspections of steam drums for power generation
- Root corrosion in piping welds
- High temperature weld inspection (up to nearly 500 ºC!)
- Inter granular stress corrosion cracking (IGSCC) in welds
- Pre-service inspection of hundreds of heavy wall vessels (up to 350 mm)
- Pre-service inspection of thousands of piping welds
- Pre-service inspection of duplex pipeline welds
- Pre-service inspection of spherical storage tanks
- Inspection of partially finished welds during fabrication at pre-heat temperature

TOFD Principle

Ultrasonic probes are positioned on either side of the weld, one acting as a transmitter and the other a receiver. The longitudinal sound beam may encounter obstacles along its path which cause reflected and diffracted signals (figure 1 and figure 2). When the probes are moved in a parallel motion along the weld, the resultant waveforms are digitized, stored on hard disk and displayed on the video-screen as a grey scale image (Figure 3). The image provides a sectional view through the weld and can be used for accurate sizing and monitoring of indications.

Figure 1: Diffraction signals during TOFD inspection.

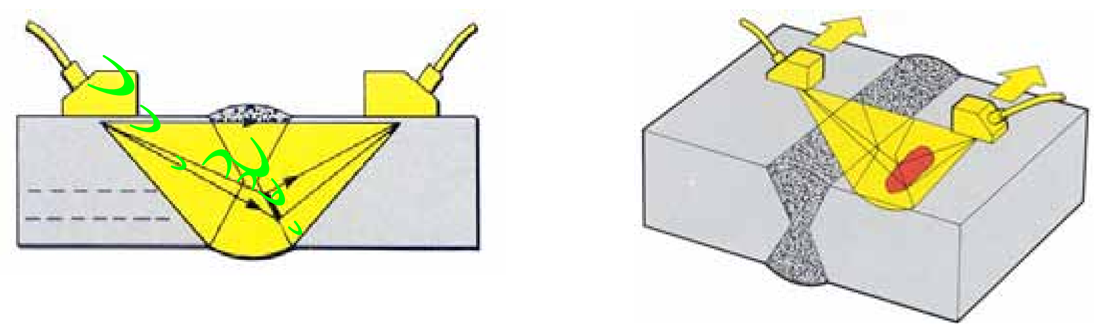


Figure 2: TOFD principles.

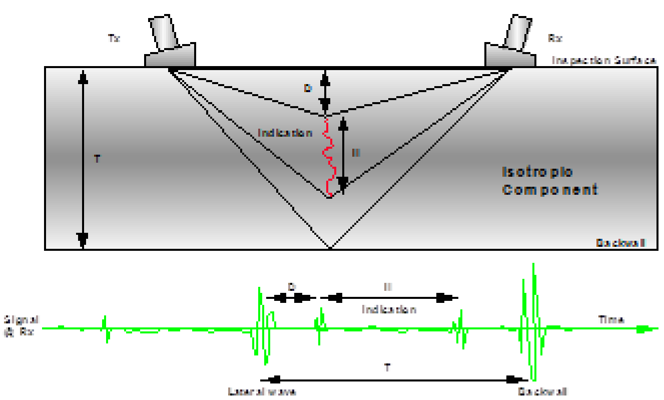
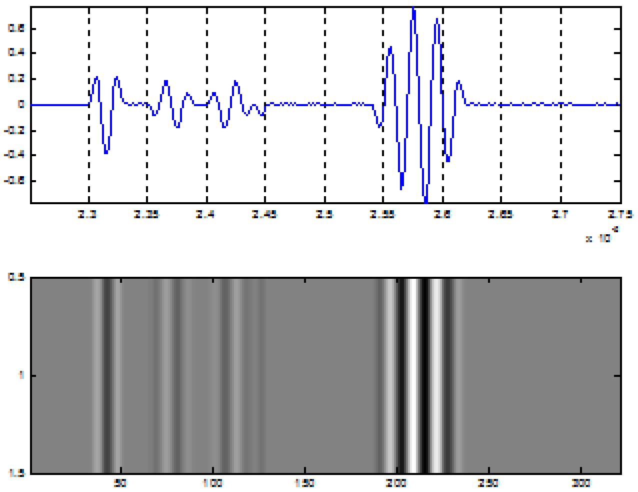


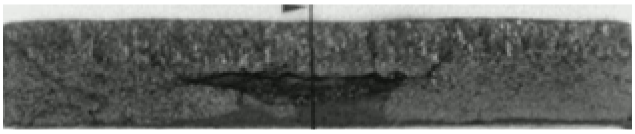
Figure 3: A scan to grey-level plot.



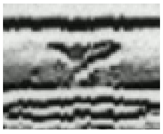
Data Storage and Reporting

All data collected with the TOFD system is stored for future reference. Data can be made available on optical disc or CD upon demand. Analysis software is also available should the client require any further evaluation of the data. Read-only data and reports are available in a format compatible with the most commonly used inspection and maintenance data management systems.

For standard pre-service inspection, pre-formatted reports tailored to client and/or authorities QA/QC requirements are provided.



Picture of a weld defect in a 6mm plate



Part of a TOFD scan of the after destructive testing defect in a 6 mm plate

Personnel

Using an in-house accredited training system, TÜV Rheinland Sonovation has trained its own operators in the theory and practical use of TOFD since the start of operation in the late 1980's. Today, training has been extended to include programs for industry technicians and suitable courses aimed at managers seeking a better understanding of TOFD and its applications.

All TÜV Rheinland Sonovation personnel performing TOFD pre-service inspections are fully trained and conversant in the techniques and equipment according to the procedure. They are qualified in accordance with the TÜV Rheinland Sonovation "Written Practice for the Qualification and Certification of NDT Personnel" introduced in 1988/1989, which fulfills the requirements of ASNT's SNT TC 1a and conforms to BS 5750 and ISO 9000 quality systems for training and certification, as well as the requirements for ASME Code Case 2235, and ASME XI edition 1992, appendix VII for nuclear applications where necessary or applicable

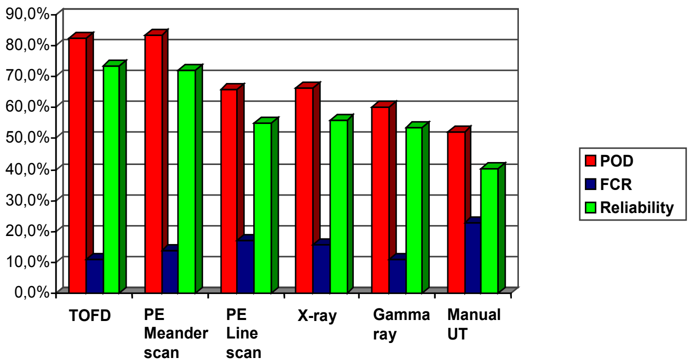
The TÜV Rheinland Sonovation system has been brought fully in line with the requirements of the ISO 9712 standard (Former European standard EN 473), which regulates the qualification and certification of TOFD operators and the independent examination required by the European Pressurized Equipment Directive. Training courses are available at both TÜV Rheinland locations and client premises.

TOFD Economy

Reliability

In comparison with other techniques, the TÜV Rheinland Sonovation TOFD method has been demonstrated to be efficient in proof of coverage, probability of detection and false call rate. During a multi-sponsor project executed in The Netherlands under the auspices of NIL (the Dutch welding institute) and KINT (the Dutch society for inspection, non-destructive testing and quality surveillance), it was determined that TOFD was the most reliable technique for pre-service weld inspection.

The reliability of inspection techniques can be defined by calculating the product of the probability of detection and the reciprocal value of the false call rate (1-FCR). During the NIL/KINT thin-plate project, the following values were derived for different inspection techniques as a result of examinations of welded plates in a thickness range of 6 to 15mm, containing some 250 implanted weld defects.



All plates were examined with the techniques shown here and later the results were verified by destructive testing. Collected data resulted in manual pulse-echo ultrasonic examination detecting slightly over 50% of the defects present. However, in about 23% of the cases, manual pulse-echo reported defects where no irregularities could be confirmed (FCR).

In addition, it is clear that X-ray techniques were more sensitive than gamma-ray techniques. But, for this improved probability of detection one pays with a higher false call rate (FCR), which results in an actual X-ray reliability figure only 2% higher, than that for gamma-ray.

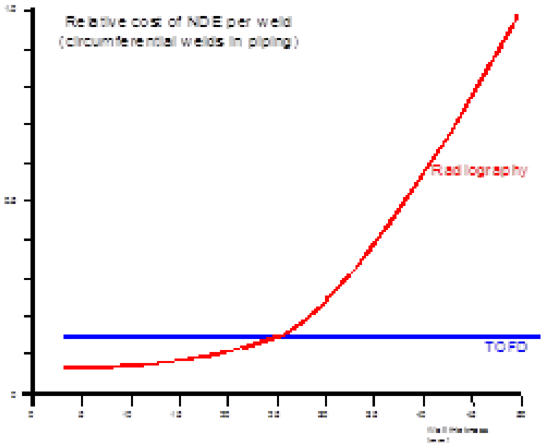
Mechanized pulse-echo examination based upon line scanning, whereby several probes are moved in parallel to the weld at different distances to the weld center line, delivers reliability comparable with the radiographic techniques.

Two techniques however deliver a much higher probability of detection and reliability: TOFD and mechanized pulse echo raster scanning. TÜV Rheinland Sonovation used the Microplus system to perform examinations. It was proven that the mechanized pulse echo meander technique results in the highest probability of detection and TOFD delivers the lowest false call rate. The reliability derived from these figures is indicates only a 1% difference. One thing to consider is that the time required for pulse echo meander scanning examination, including the subsequent analysis of the data and the reporting thereof, took much more time than the same for the TOFD technique.
As a result, the costs for this type of examination will in most cases are a factor 10 higher than Time of Flight Diffraction. Because pulse echo raster scan examines the entire weld volume with several angle probes (not only directed at the weld preparation) such that defects of many different orientations are detected, its reliability score is quite good. This contrasts with line scanning, which seeks a compromise between the number of probes required to inspect at all depths and angles of incidence and the number of probes admissible within the physical and economical constraints. The ability of diffraction signals to scan the whole weld volume in a one-line examination provides TOFD with its excellent reliability score.

Price and Cost

TOFD inspection speed is extremely high and practically unaffected by weld thickness. Whether a weld is 6 mm thick or 50 mm, it can still be examined in a single pass of the probes. During a project in 1995/1996, a manufacturer of piping welds determined TOFD inspection was actually cheaper than radiography for wall thicknesses of 25mm or more, as illustrated in the following graph which compares relative inspection prices and wall thickness for welds in piping:

During recent years, more availability of TOFD, ever-increasing speed of computing power and practical experience gained have substantially reduced the price for TOFD inspection. Similarly, due to increased emphasis on radiation safety, the price of radiography has steadily increasing direct and indirect costs. These factors have pushed the current break-even point even lower, to approximately 15 mm wall thickness.



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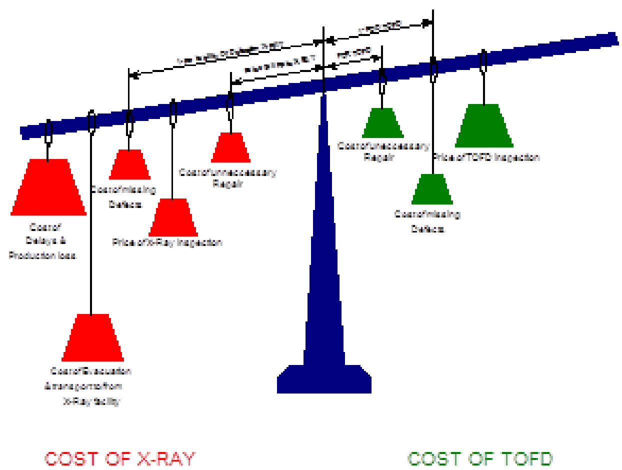
However, true cost comparison should not only be based on the inspection price per weld, but should include the following factors to arrive at a total inspection cost:

- As no ionizing radiation is used, savings of several weeks in construction time on most projects is standard.
- Inspection does not interfere with the construction program.
- During the prefabrication stage the sometimes very large pipe spools can be inspected at the welding location without the need for moving them to an X-ray facility, saving the manufacturer considerable transportation cost and providing more flexibility in production planning.
- Because large areas do not need to be evacuated for inspection, round-the-clock welding can take place during site construction.
- The cost of missing a defect can be enormous, especially when an undetected defect leads to an unplanned shutdown.
- If a method has a high false call rate, this will inevitably lead to unnecessary repairs. The proven TOFD low false call rate keeps such action at a minimum.



- All data is stored both as hard copy and in digital form in order that source data can be compared to future inspections, allowing for accurate flaw growth measurements which can be used in a risk- based inspection planning approach. The high accuracy of TOFD, providing more accurate predictions of when follow-up inspections are needed, often results in longer inspection intervals and extended asset lifetime.

Procedures and Specifications

To fully implement TOFD, it is necessary to have officially recognized procedures to follow. Over the years, several such procedures have been developed and have led to officially recognized standards and specifications:

- Method description
  - British Standard 7706: Calibration and setting-up of the ultrasonic time-of-flight-diffraction (TOFD) technique for the detection, location and sizing of flaws
  - ENV 583 pt6: Non Destructive Testing – Ultrasonic Examination – Part 6: Time-of-flight diffraction technique as a method for detection and sizing of discontinuities

- Weld inspection technique specification
  - PrCEN/TS 14751: Welding – Use of time-of-flight diffraction technique (TOFD) for examination of welds
  - Code case 2235: Case of ASME Boiler and Pressure Vessel Code section I and section VIII, Divisions 1 and 2, Use of Ultrasonic examination in Lieu of Radiography

- Acceptance criteria
  - NEN 1822: Acceptance criteria for the time of flight diffraction inspection technique (Formerly TO 97-50 rev 1)
  - Code Case 2235: Case of ASME Boiler and Pressure Vessel Code section I and section VIII, divisions 1 and 2- use of ultrasonic examination in lieu of radiography

- TÜV Rheinland Sonovation uses its unique, self-developed ScanPlan system to support TOFD inspection procedure preparation and coverage demonstration. This software suite not only helps experts to optimally configure TOFD inspection, but also aids in reporting and functions in accordance with the main industry standards.

Acceptance Criteria

When TOFD is used as a pre-service inspection technique during fabrication, the following options are currently available:

- The use of TOFD for detection, in combination with conventional techniques such as manual UT for evaluation in accordance with an existing code.

- A job-specific translation by a Level III qualified person, of existing acceptance criteria in use for the conventional NDT techniques such as manual pulse echo and/or radiography to TOFD acceptance criteria.

- The use of acceptance criteria in Dutch National Standard NEN 1822, developed within the Dutch acceptance criteria project by the Dutch Quality Surveillance and Non-Destructive Testing Society (KINT) and the Dutch welding institute (NIL).

- The use of the ASME code case 2235 for wall thicknesses from ½“(12.7mm).

In 1998, the Dutch Quality Surveillance and Non Destructive Testing Society, KINT completed the TOFD acceptance criteria project. Several major Dutch industrial partners in the oil and gas, chemical and other industries sponsored this project. These acceptance criteria are based on good workmanship and details of the project are available on request.
The acceptance criteria have been tested both in a fracture mechanics model, and by comparison of the results of parallel tests with both conventional techniques and TOFD in the field.

Rejection rates were proven to be not significantly higher and the integrity of the construction to be always higher than when conventional techniques are used.
These acceptance criteria are now available as a Dutch national standard (NEN 1822), and have been proposed as European acceptance criteria.

TOFD in the Field

TOFD, combined with the specific acceptance criteria, has been used in the field for the inspection of thousands of welds in several major constructions and replacement projects in the (petro-) chemical industry and the power generation industry. These projects have proven that the use of TOFD can save precious time.

Some Examples:

A project at a refinery in Rotterdam was finished two weeks earlier than planned, because by using TOFD in lieu of radiography, the weld inspection was no longer on the critical path but could instead take place in parallel to other work. Construction time for a chemical industry project was reduced due to the fact that repairs could be carried out in an early stage. By implementing TOFD for the inspection of the root, before completion of the welds in heavy wall piping, costly repairs at the final stage were avoided.

TOFD can also be cost-effective on thin wall. A project in the power generation industry was carried out on piping from 4” with a 6 mm wall thickness and more. The elimination of ionizing radiation allowed for construction work unhindered by radiography to significantly reduce the duration of the project.

These projects also illustrated that the repair rate was not higher compared to projects using conventional techniques.

For practical site work, TOFD data is presented in an easily understandable format, ready for inclusion in inspection and data management systems. The way in which the results are reported is kept much the same as the radiography reporting. After a short introduction, client inspectors are able to work quite easily and accurately with the TOFD reporting.

Did you know?

TÜV Rheinland Sonovation has over twenty years of experience with advanced non-destructive testing. Our inspection team is one of the best resourced in the world. Our involvement is equipment development, inspection solutions and accredited training courses demonstrate our commitment to these techniques.

About TÜV Rheinland:

Founded more than 150 years ago, TÜV Rheinland is a global leader in independent inspection services, ensuring quality and safety for people, the environment, and technology in nearly all aspects of life.

TÜV Rheinland InterCert Kft. - Hungary
Industrial Services Department
Material Testing and Condition
Monitoring Laboratory
H-2440 Százhalombatta,
Műszerész köz 6.
telefon: +36-1-461-1168
anyagvizsgalat@hu.tuv.com
www.tuv.hu

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