Main Issues of the European TOFDPROOF Project

Daniel CHAUVEAU, Didier FLOTTE, IS Services, Paris, France
Christian BOUCHER, Institut de Soudure, Paris, France

Abstract. The European TOFDPROOF project (contract n° G6RD-01-00626., 2002 - 2005) aimed at producing a coherent package of E.U. agreed documents (procedures for applying TOFD with related acceptance criteria and recommendations for training and certification) based on a Round Robbin Test performed on welded specimens and validated through site trials. The project was focused on all aspects allowing the effective application of the TOFD as a stand-alone method for the weld inspection during manufacture of pressure equipment. Technological, regulatory, human factors were considered. The performance of TOFD was compared with conventional NDT as defined by European standards for testing pressure vessels at the manufacturing stage. This evaluation was carried out by means of a Round Robbin Test on welded specimens. All the results generated by this round robin exercise was stored in a data base set up on a Web site. Results produced were in a suitable form for implementation in CEN standards and dissemination among NDT specialists. Specific tools analysis was developed in order to enable a quick and reliable comparison of the TOFD results with those obtained by conventional NDT. Optimised TOFD procedures and specific related acceptance criteria were developed and applied. The influence of the objectiveness of TOFD inspectors were assessed after to have been trained with an interactive training guideline developed through the project and based on TOFD images collected from the Round Robbin Test. Recommendations for training and certification of personal were written and distributed to the NDT society, the relevant standardisation CEN technical committees and the EU companies dealing with weld inspection. TOFD with the corresponding acceptance criteria were then applied on site on welded components in order to demonstrate the technical efficiency and cost competitiveness compared with conventional NDT. The economical analysis confirms that TOFD can be less expensive than conventional NDT techniques to inspect welds.
1. Introduction

Various national TOFD evaluation projects have demonstrated that TOFD combines a high probability of detection with a low false call rate and would thus ensure improved quality control at the manufacturing stage.

It has however been recognised that the effective industrial application of TOFD as a widely applied stand-alone NDT method would not be possible unless:

- a European methodology for weld inspection is defined,
- weld defect acceptance criteria would be specified,
- guidelines for training and qualification of operators would be available.

In addition, while insuring better inspection, better working conditions and respect of the environment, the method, taking account of economical aspects, would not result in more statistical flaw rejection rate than radiography.

2. Objectives and strategic aspects

A European programme called TOFDPROOF supported by EPERC was launched by Institut de Soudure. A consortium of ten members representing seven European Countries has been formed: Institut de Soudure (France), IS Services (France), Sonovation (The Netherlands), TWI (Great Britain), Mitsui Babcock Energy (Great Britain), MPA (Germany), Tecnatom (Spain), VTT (Finland), ISQ (Portugal), TÜV (Germany).

The TOFDPROOF project objective was to implement the TOFD technique (Time Of Flight Diffraction) as a routine NDT technique for weld inspection at the manufacturing stage of pressure equipment. The project was focused on all aspects allowing the effective application of the TOFD as a stand-alone method. Technological, regulatory, human factors were considered.

The project was centered on:

- the problem of detection and classification of defects in welds, both transverse defects (cracks) and axial defects (i.e. porosity, inclusions, lack of penetration, lack of fusion, cracks).
- the design of related acceptance criteria directly usable with the potential of the TOFD images. The project covered: non alloyed and low alloyed ferritic steels, butt welds (piping and plates), thickness range: 6 to 100 mm with emphasis on 10 to 60 mm, and manual arc, TIG, submerged arc welding.

The project aims at producing a coherent package of E.U. agreed documents (procedures for applying TOFD with related acceptance criteria and recommendations for training and certification) based on a round robin testing performed on welded specimens and validated through site trials.

To reach this target the following objectives were pursued:

- to compare TOFD performance with conventional NDT as applied according to the European standards defined by CEN TC 121 "Welding",
- to define the field of application of TOFD, highlighting weaknesses and strengths; if applicable,
- to optimise the methodology of application in order to ensure reproducible inspections with different pieces of equipment and inspectors,
- to verify how TOFD allows for detection of transverse defects,
- to develop acceptance criteria,
- to perform an economic analysis of inspection costs compared with conventional NDT methods,
- to define a framework for operators qualification and certification.

3. Project organisation and main results

3.1 Introduction

A dedicated web site: http://www.mpa-lifetech.de/tofd/HTML_Files/Main/TOFDDefault.htm provides information about the main results obtained and the public deliverables.

The project work plan involves seven work packages (WP) interrelated as shown Fig 1, in order to obtain an agreed European position concerning the performance of TOFD inspection, the procedures for applying TOFD, the needs for training and certification and the design and validation of acceptance criteria.

Fig1 : Synoptic of the project
3.2 Trials organisation and justification of representative specimens

To collect an indisputable set of NDT results from welds was a pre requisite. The larger welded samples collection as possible was necessary to prepare very carefully the NDT to carry out.

As a first step the partners reviewed the available welded samples in their premises. 117 weld defects corresponding to 32 existing test specimens were finally retained for the round robin trials. A preliminary assessment shown that to cover all representative weld defects type, size, weld geometry and thickness and to perform a relevant statistical analysis of the results would require at least 150 defects weld defects. 33 defects in 13 new specimens were then manufactured to complete the test specimen collection.

3.3 Round Robin Test

3.3.1 Description

A round Robin testing involving the ten partners was performed on these welded specimens containing real weld defect of various types and sizes. On a whole 150 weld defects were collected, of which 33 were manufactured for the project testing programme. The number of tests and the blind trials criteria (objectivity, neutrality, no overlapping…) required a tight management achieved by means of a detailed test matrix, completed by the use of detailed testing protocols including data transmission and storage in the TOFDPROOF website. The blind trials required 961 tests covering all NDT methods, of which 395 TOFD testing. These tests have been shared according to thickness range and NDT techniques according to Fig 2.

A test was defined by the combination of a test performer team, an NDT method (UT, X-rays, γ-rays Ir192, accelerator and TOFD), a defect type, and an acceptance criteria level. Blind trials as project mainstay required a very careful preparation. As a matter of fact it was necessary to make available the same set of NDT data (TOFD, RT and UT) on the same defect to allow a reliable comparison. A certain amount of redundancy was introduced in the various NDT experiments. Specific tools for analysis were developed in order to enable a quick and reliable comparison of the TOFD results with those obtained by conventional NDT. This comparison was performed using Probability Of Detection (POD) curves and statistical analysis tools.

Figure 2 : Blind trials organisation
3.3.2 Design of conventional NDT procedures

A series of conventional NDT procedures were produced to be applied by the various teams involved in the project:
- Ionising radiation procedures based on standards EN1435, EN444, EN12517:
  - X-Ray procedure, “Procedure for X-ray inspection of test blocks in TOFDPROOF-project”
  - Gamma-rays, “Radiographic Testing with Isotopes Procedure”

These procedures were reviewed by a working group composed of most of the partners.

3.3.3 Design of the TOFD procedures

The partners involved in TOFD inspection designed a common TOFD procedure. The choice of the set-up to apply (PCS, probe frequency …) according to the sample thickness was made on the results of beam coverage modelling (Fig 3).

![Figure 3: Example of results of beam coverage modelling](image)

200 cases in terms of thickness, probe diameter, probe frequency, refraction angle were studied. Tables of recommended values were produced as shown in Table 1 below.

<table>
<thead>
<tr>
<th>Thickness t / mm</th>
<th>Number of TOFD set-up</th>
<th>Depth-range ∆t / mm</th>
<th>Centre frequency f / MHz</th>
<th>Beam-angle °</th>
<th>Element mm</th>
<th>Beam intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-10</td>
<td>1</td>
<td>0-t</td>
<td>15</td>
<td>70</td>
<td>2-3</td>
<td>2/3 of t</td>
</tr>
<tr>
<td>&gt;10-15</td>
<td>1</td>
<td>0-t</td>
<td>15-10</td>
<td>70</td>
<td>2-3</td>
<td>2/3 of t</td>
</tr>
<tr>
<td>&gt;15-35</td>
<td>1</td>
<td>0-t</td>
<td>10-5</td>
<td>70-60</td>
<td>2-6</td>
<td>2/3 of t</td>
</tr>
<tr>
<td>&gt;35-50</td>
<td>1</td>
<td>0-t</td>
<td>5-3.5</td>
<td>70-60</td>
<td>3-6</td>
<td>2/3 of t</td>
</tr>
<tr>
<td>&gt;50-100</td>
<td>2</td>
<td>0-t/2</td>
<td>5-3.5</td>
<td>70-60</td>
<td>3-6</td>
<td>1/3 of t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>t/2-t</td>
<td>5-3.5</td>
<td>60-45</td>
<td>6-12</td>
<td>5/6 of t for 60° or t for 45°</td>
</tr>
</tbody>
</table>
Two new designs were proposed for the reference blocks, one with side-drilled holes and one with notches.

A proposal of classification of relevant indications was done by analysing the following features: disturbance of the lateral wave, disturbance of the back wall echo, signal phase pattern between lateral wave and back wall echo, mode converted signal after the first back wall reflection. The indications were classified as follows:

- Surface breaking discontinuities
- Embedded discontinuities (point like, elongated without measurable height, elongated with measurable height)
- Unclassified.

Several TOFDPROOF consortium members being TC121 ad-hoc group experts also in charge of the preparation of the technical specification XP CEN/TS 14751 “Welding – Use of time-of-flight diffraction technique (TOFD). Many items of the TOFDPROOF procedure were proposed as a starting point to draft the CEN specification: scanning of welded specimens; TOFD image interpretation; table of set-up; analysis, classification and evaluation of indications; design of reference blocks.

In order to optimise the comparison of the results obtained by each team, it was decided specific templates would be used for reporting. The whole results were stored in a data base for analysis (see example Fig 4 and table 2).

![Example of TOFD image obtained](image-url)
Table 2: TOFD interpretation of Fig 5

<table>
<thead>
<tr>
<th>Indication</th>
<th>Type</th>
<th>Beginning (mm)</th>
<th>End (mm)</th>
<th>Top position (mm)</th>
<th>Height (mm)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Embedded</td>
<td>0</td>
<td>35</td>
<td>11</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Embedded</td>
<td>45</td>
<td>62</td>
<td>13</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Embedded</td>
<td>63</td>
<td>74</td>
<td>11</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Embedded</td>
<td>25</td>
<td>110</td>
<td>7.5</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Surface breaking</td>
<td>112</td>
<td>131</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Embedded</td>
<td>99</td>
<td>115</td>
<td>11</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Embedded</td>
<td>145</td>
<td>155</td>
<td>7</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Embedded</td>
<td>150</td>
<td>193</td>
<td>11.5</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Embedded</td>
<td>195</td>
<td>223</td>
<td>9</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

3.4 TOFD results and discrepancies analysis

Following the round robin trial exercise and the reporting of the results, the TOFD data were collated and a review focusing on the causes of discrepancies in the results was carried out in order to highlight the strengths and weaknesses of the TOFDPROOF technique.

The main identified limitations of the procedure are:

- the defect categories need to be better defined and consideration should also be given to additional categories e.g. multiple indications.

- where a defect extends before and after a datum, an extra scan covering the entire defect area (without a break) should be carried out in order to provide a more accurate value of the defect length.

- it became clearer after the review of the analysis that high frequency small crystal diameter probes (15MHz, 3mm) should be recommended for the inspection of thin samples (up to 15mm) especially when the weld surfaces are as-welded, an alternative choice (e.g., 10MHz) may not be appropriate.

- high frequency (15MHz) probes provided a better means of detection and evaluation of defects which are surface breaking or just below the surface.

- it is well known that one of the TOFD technique limitations is the surface inspection (upper and rear surfaces). The presence of the lateral wave and the back wall echo restrict the inspection zone. Small defects in these zones can be missed.

- Inspection for transverse indications can be limited especially when the weld cap is still present. Transverse indications were in general not reported or wrongly reported as point-like or as longitudinal defects. When transverse defects are expected and the weld is as-welded, additional technique(s) should be used.

The TOFDPROOF procedure has then been optimised. The main items modified are listed hereafter:

- the maximum allowed frequency should be considered first. The lower frequencies may be used if the required sensitivity setting cannot be achieved with the upper frequencies,

- the techniques to measure length and height have been clearly defined. This part of the procedure has also been added in the proposal of the acceptance criteria and in the recommendation for applying TOFD,
- when the specific pattern (replication of mode converted signals) as shown Figure 5 is observed one can conclude to the evidence of a transverse defect.
- The end of time window shall be at least 1 μs after the 1st mode converted signal

![Figure 5: TOFD image obtained on a sample containing 3 transverse defects](image)

### 3.5 Recommendation for applying TOFD

The recommendations based on the TOFDPROOF project round robin results and the limits identified during the study were fully reported. Additional considerations must be taken into account when different material and component geometry are under study.

The recommendations (completed with observations) were provided for seven categories, including: procedure, identification of reference marks, set-up, classification of indications, evaluation of indications, personnel qualification and acceptance criteria. For each category, comments and recommendations were provided.
Example of some of them are given hereafter:
- a specific procedure shall be written in accordance with the guidelines given in ENV 583-6 and XP CEN/TS 14751 for each individual type of inspection,
- the identification and inscription of reference marks (including datum on the component and reference point on the inspection probes array) is critical to allow repeatability of the inspection and results comparison,
- the indications shall be classified into categories clearly defined in the inspection procedure.
- for interpretation of the images, initial analysis has to be carried out on unprocessed data. Straightening and removal (for lateral wave and back wall echo) tools can be use for subsequent analysis e.g. confirmation of presence/absence of surface defects.

These recommendations were transferred to CEN TC121, TC54, TC138 and EPERC.

Although the TOFD method is considered as the better performing NDT method, some weakness remains:
- TOFD cannot guaranty the detection of transverse defects when a single scan is used because an upper transverse defect may be mistaken with a point like defect; however transverse defect characteristic TOFD patterns can be observed; in this case a complementary technique shall be applied (TOFD with skew angles, pulse echo in pitch and catch with skew angles …).
- the lateral wave and the back wall echo may restrict the inspection zone in some cases:
  - the minimum dead zone (lateral wave side) depends mainly on frequency, PCS, probe bandwidth and surface conditions,
  - the minimum detection limit (back wall side) depends mainly on surface variations, probe frequency, offset scanning …)
- surface breaking defect and subsurface defect can be mistaken.

3.4- Guidelines for training, qualification and certification

An interactive training guideline for interpreting TOFD images was produced. This is in the form of computer software and contains a database of more than 25 typical TOFD images.

This guideline is made in 3 parts:
- basic principles of TOFD are recalled
- TOFD image assessment methodology
- TOFD indication classification and sizing methodology

Unfortunately, this last part doesn’t take into account the optimising sizing techniques recommended in the optimised procedure. The link between the TOFD image and the A-Scan has not been implemented, but this software remains a very nice tool for training purpose.

The ‘training’ part of the software teaches the inspector to identify significant defects on a TOFD image and to correctly determine their type and dimensions (length and height). As well as the training part, the software also contains a “testing” part that has been used to assess the objectivity of the inspector’s interpretation of TOFD images.
Any discrepancies seen in the results, during the objectivity assessment, have been fed back to the guideline designer to enable the interactive training guideline to be improved and updated.

The interactive training software can be used on line free of charge on the web site:  
http://www.mpa-lifetech.de/TOFD

An example of a screen is given in figure 6.

![Example of screen when using the interactive training guideline](image)

**Figure 6**: Example of screen when using the interactive training guideline

### 3.4-Objectivity assessment

TOFD inspectors from the TOFDPROOF partners have taken part in the objectivity assessment, and the results of this exercise have been analysed. The main conclusions, before optimising the TOFDPROOF procedure are given here after:

a) The greater degree of confusion is observed in the defects type E (elongated without measurable height) and D (point like). For defects type E it is easily understandable as there is not any E type defect in Training Guideline Training Session as an example.

b) For each defect it is observed a tendency in the different teams in sizing the defects by excess or by defect. This is clearest observed in length sizing.

c) In order to improve the operator capability for defect characterization and sizing, it would be recommendable to increase the number of defects specially types E, D, and F (elongated with a measurable height), for training purposes.
These limitations should have been overcome if the images have been reassessed according to the optimised procedure.

3.5 Recommendations for TOFD training and certification

Two documents containing recommendations for TOFD training and certification have been produced. These have taken account of existing certification schemes in the UK (administered by PCN) and The Netherlands (administered by SKO). These documents can be uploaded from the TOFDPROOF website: [http://www.mpa-lifetech.de/TOFD](http://www.mpa-lifetech.de/TOFD)

Recommendation concerning requirement to train and certify TOFD personal have been written and transmitted to TC 138 and are summarised here after:

Minimum Training Requirements

<table>
<thead>
<tr>
<th>Level</th>
<th>Duration (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>3 Days (24)</td>
</tr>
<tr>
<td>Level 2</td>
<td>5 Days (40)</td>
</tr>
<tr>
<td>Level 2 (direct)</td>
<td>8 Days (64)</td>
</tr>
</tbody>
</table>

Minimum Experience Requirements

<table>
<thead>
<tr>
<th>Level</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>3 Month</td>
</tr>
<tr>
<td>Level 2</td>
<td>6 Months</td>
</tr>
</tbody>
</table>

3.6 Acceptance criteria definition

Acceptance criteria definition in accordance with EN ISO 5817 was designed and proposal of tables designed by the TOFD experts of the consortium, meeting the various levels as defined in EN ISO 5817 and EN 12062 have been produced (see table 5 below).

The proposal consists of TOFD acceptance criteria for three acceptance levels related to the quality levels according to EN ISO 5817 (table 3 below).

<table>
<thead>
<tr>
<th>Quality level according to EN 5817</th>
<th>Acceptance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (Stringent)</td>
<td>1</td>
</tr>
<tr>
<td>C (Intermediate)</td>
<td>2</td>
</tr>
<tr>
<td>D (Moderate)</td>
<td>3</td>
</tr>
</tbody>
</table>

The proposal of acceptance criteria is linked to the capability of classification of defect with TOFD as specified now in EN XP TS 14751 and illustrated in figure 7.

![Figure 7 : TOFD capabilities concerning defect classification](image-url)
For single discontinuities, the proposal of acceptance criteria approved by the TOFDPROOF consortium is given in tables 4 to 6 below.

Table 4 - Acceptance criteria for acceptance level 1

<table>
<thead>
<tr>
<th>Thickness range</th>
<th>Lmax [mm]</th>
<th>h3 [mm]</th>
<th>h2 [mm]</th>
<th>h1 [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6mm&lt; (d_d) ≤ 15mm</td>
<td>0.75 (d_d)</td>
<td>1.5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>15mm&lt; (d_d) ≤ 50mm</td>
<td>0.75 (d_d)</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>50mm&lt; (d_d) ≤ 100mm</td>
<td>40</td>
<td>2.5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>(d_d) &gt; 100mm</td>
<td>50</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5 - Acceptance criteria for acceptance level 2

<table>
<thead>
<tr>
<th>Thickness range</th>
<th>Lmax [mm]</th>
<th>h3 [mm]</th>
<th>h2 [mm]</th>
<th>h1 [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6mm&lt; (d_d) ≤ 15mm</td>
<td>(d_d)</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>15mm&lt; (d_d) ≤ 50mm</td>
<td>(d_d)</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>50mm&lt; (d_d) ≤ 100mm</td>
<td>50</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>(d_d) &gt; 100mm</td>
<td>60</td>
<td>4</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 6 - Acceptance criteria for acceptance level 3

<table>
<thead>
<tr>
<th>Thickness range</th>
<th>Lmax [mm]</th>
<th>h3 [mm]</th>
<th>h2 [mm]</th>
<th>h1 [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6mm&lt; (d_d) ≤ 15mm</td>
<td>(d_d) x 1.5 (max. 20)</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>15mm&lt; (d_d) ≤ 50mm</td>
<td>(d_d) x 1.5 (max. 60)</td>
<td>2.5</td>
<td>4.5</td>
<td>2</td>
</tr>
<tr>
<td>50mm&lt; (d_d) ≤ 100mm</td>
<td>60</td>
<td>4</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>(d_d) &gt; 100mm</td>
<td>75</td>
<td>5</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>

Where:
- \(l\): length of an discontinuity
- \(h\): height of an discontinuity
- \(d_d\): nominal wall thickness in accordance with construction drawing or dimension table

The laws to consider discontinuities as a group are also given. These laws depend on the acceptance level. A maximum accumulated length is given for discontinuities: 10% of the total weld length with a maximum of 500 mm. The methods to measure the length and the height of an indication are given as in the recommendation document.

3.7 Rejection rate comparison

In addition, work has been carried out to compare the TOFD rejection rate when applying the present acceptance criteria proposal to RT and UT rejection rates when applied according to CEN standards. To this end the different NDT techniques were simulated in a probabilistic model and fracture mechanics assessments will be performed for different sample geometries, loading conditions, material data and defect configuration.
In these simulations a structure with a population of defects is inspected with TOFD and other NDT techniques. Depending on the performance of the applied NDT technique and on corresponding acceptance criteria, a certain percentage of the total number of defects will have to be rejected. The number and types of rejectable defects largely depend upon the applied NDT technique.

With use of the ALIAS software the probability of detection (POD) and the population distribution of flaws (PDF) were computed from the available TOFDPROOF database collected during the Round Robin Trials, and compared with those obtained in the frame of the KINT project. (table 7)

Table 7 : POD and FCR results

<table>
<thead>
<tr>
<th></th>
<th>POD KINT project</th>
<th>POD TOFDPROOF project</th>
<th>FCR KINT project</th>
<th>FCR TOFDPROOF project</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOFD</td>
<td>82.4% 70 to 90%</td>
<td>11.1% &lt;10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT Inspection</td>
<td>60.1% 60 to 70%</td>
<td>Not assessed</td>
<td>Not assessed</td>
<td></td>
</tr>
<tr>
<td>Manual UT</td>
<td>52.3% 55 to 65%</td>
<td>Not assessed</td>
<td>Not assessed</td>
<td></td>
</tr>
</tbody>
</table>

It was demonstrated that the final proposal for TOFD acceptance criteria leads to a better or equal quality level than conventional NDT meeting the stated conditions:
- a better or equal probability of failure compared to conventional NDT
- an equal or lesser percentage of rejections for TOFD compared to conventional NDT

3.8 Economic analysis

An economic analysis to compare direct and indirect costs (with reference to conventional NDT) using TOFD inspection related to the acceptance criteria proposal and for the various levels proposed was proposed. This analysis took into account:
- the direct cost of the inspection (day or night working) based on an average rate for the inspector, the equipment, consumable…
- the indirect cost of the inspection induced by false calls, time to access to results…
- the cost of purchase and maintenance of the equipment and of training of the personnel…
- the manufacturing disturbance caused by the NDT applied
- the productivity gains.

Each partner involved in the consortium supplied the estimated average costs in use in his own country related to several industrial components. To this purpose representative case studies were defined:
- Vessel of 2000 mm Diameter; length 10m, thickness 36mm, 50mm, 100mm; number of welds to be investigated, 3 circumferential welds and 2 longitudinal welds. (cost per m weld). A cost per meter of weld inspected was supplied for TOFD, RT, UT and for 3 different thickness: 36mm, 50mm, 100mm.
- Piping Diameter 20 inch, thickness 6mm, 15mm, 36mm. (cost per circumferential weld for total of 10 welds). A cost per circumferential weld for a total of 10 welds) was supplied for TOFD, RT, UT and for 3 different thickness : 6mm, 15mm, 36mm
The costs of a TOFD inspection was compared with the direct and indirect costs generated when using:

- Manual UT applied according EN 1714 and EN 1713 (acceptance criteria according EN 1712 – level 2 + no planar imperfection accepted)

- X-rays applied according EN 1435 (acceptance criteria according EN 12517 – level 1 and 2 + table 6.5.3.2.1 from Pr EN 13445).

It follows that TOFD (Fig 7) is by far the cheapest inspection method, even if the price for inspection is assumed to be higher than for other techniques.

4. Conclusions

All project objectives have been achieved.

Many items of the original TOFDPROOF procedure were used in the CEN technical specification related to TOFD weld inspection. XP TS 1A 751 issued in January 2005. Acceptance criteria were proposed taking into account the Quality level defined in EN ISO 5817: 2003) and acceptance levels as B/1 , C/2, D/3.

These acceptance criteria are easy to use and based on indication category as defined in XP TS 14751, and length, height and thickness ranges: 6 to 15, 15 to 50, 50 to 100, > 100 mm. This proposal was the starting point for the CEN standardisation now at the public inquiry stage.

An interactive training guideline has been designed and can be used on line free of charge on the dedicated web site.

TOFD is gaining acceptance worldwide rapidly and has been introduced in many standards already. TOFD uses no ionising radiation so that TOFD inspection does not interfere with
the current production process. TOFD inspections can therefore in general take place in parallel to production work during day-shift. There is no need for transportation of pipe-spools, vessels or other parts to an X-Ray facility; the associated logistic problems and cost do not exist. Thickness variations do not greatly affect the inspection speed. Very thick materials can be examined in the same fast and efficient manner.

TOFD data are very accurate and reproducible and are presented in a format which is easily understood. Insensitivity to defect orientation, together with encoded positioning leads to improved inspection sensitivity and accuracy which results in optimised reproducibility.

Despite some remaining weaknesses, TOFD, when applied according to an appropriate procedure and by well trained personal (this is not restricted to TOFD inspection) is a NDT-method to challenge the detection of weld defects at the manufacturing stage, even with respect to economics.

Acknowledgements

The TOFDPROOF partners express their thanks to the Directorate General Research for co-financing the TOFDPROOF project under contract n° G6RD-01-00626.