 AUTOMATIC ULTRASONIC INSPECTION OF PIPELINE GIRTH WELDS WITH A CORROSIVE RESISTANT ALLOY (CRA) LAYER

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Abstract

Development of the Norne Satellite Field comprises the connection of the two oil fields Stær and Svale to the Norne FPSO (see Figure). A unique solution, a common, single pipeline was selected by Statoil for transport of the multiphase well stream from the two oil reservoirs. The Norne field is located at 66° North and subjected to strict environmental requirements. Therefore a Carbon steel pipeline, built with a corrosive resistant alloy layer (CRA), had been selected for the resistance against the corrosive fluid without the use of chemicals. An implication of this construction method is that the pipeline girth welds have to be made with an austenitic welding consumable (typically Inconel), which is very difficult to inspect using ultrasonic testing method. Furthermore the reeling process used for the pipeline installation require severe weld flaw detection capabilities.

An extensive AUT-CRA qualification program has been utilized by Technip and Statoil to confirm that the proposed CRA inspection method meet the quality standards and requirements of DNV OS F101 Appendix E.

Throughout the qualification process it has been verified that the CRA inspection technique adequately detects and qualitatively sizes the weld defects that also have been observed in destructive, microscopic evaluation. The so called Primary & Coincidence CRA inspection method* has been demonstrated to be very versatile in comparison with conventional shear wave tandem techniques normally used for Carbon steel pipeline welds.

The Norne Satellite project (Statoil) in the Norwegian Sea involves a 9 km long 15” diameter insulated clad steel production pipeline. The line pipe is longitudinally welded SAWL joints of 12m length, with 21mm backing steel (X60) and 3mm metallurgical bonded 316L CRA

Approximately 788 welds at Technip’s spoolbase facility in Orkanger Norway, was inspected using the CRA AUT inspection technique, in detail described in this paper.

* Dutch patent registered under nr: 1024726, awarded in May 9th 2005 and filed for PCT application Nov 8th 2004 under nr: PCT/NL2004/000874

Figure of the Norne Field with Stær and Svale reservoirs
1. Introduction

There is very limited experience in the Offshore Pipeline industry regarding the Automated Ultrasonic Inspection of Austenitic Girth Welds with CRA layers.

The AUT inspection technique to be used for Austenitic welds having CRA layers deviates from the standard approach, which is described within internationally available AUT inspection standards. Due to the coarse grain and anisotropic structure of the weld material, special designed ultrasonic probes and adapted AUT system inspection software were required for examination of the Norne Satellite CRA welds. The “new” inspection approach was subject for qualification and validation in order to demonstrate that the proposed technique could fulfill stringent inspection requirements which are applicable for the reeling process. Experiences from former projects are difficult to find, since this was the first clad pipeline to be reeled.

To determine the overall qualification program to be performed for the Norne Satellite project, reference has been made to the existing development experiences on CRA weld inspection from the Shell Bonga project. The available defect population was obtained out of real CRA pipeline production welds and were therefore of a naturally coarse. Representatives from Technip, Statoil and DNV performed an audit at RTD premises with the objective to draw up an inventory of the performed CRA qualification work and to judge whether this work could be used for the benefit of the Norne Satellite project. It has been concluded that the existing CRA qualification work could be used to complement the Norne Satellite scope of CRA qualification work.

As a result the statistical uncertainties were reduced merging the both qualification program results (referenced qualification data and additional Norne Satellite Field qualification work).

2. Development of AUT CRA inspection technique

2.1. Pipeline configuration

The project has made use of metallurgical clad pipes, which means that the internal clad layer (316L quality) was rolled to the backing steel in a complex process. This gave atomic bonding between the backing steel and clad, which was mandatory for reeling purposes.

The pipe tolerances are very important from a production point of view. To make the best fit between two pipe ends, factors like ovality, straightness of pipes and wall thickness variations are critical to have a smooth weld without too much misalignment. When the pipes have a longitudinal seam in addition, the steel mill have a challenge in avoiding flat areas next to the seam.

A clad pipeline is chosen for its ability to resist corrosive fluids. The clad steel pipe consists of an internal corrosion resistant liner (wall thickness approx. 3mm) metallurgically bonded to the backing carbon steel pipe, see Figure 2.1. A nickel layer is applied between the CRA and the backing steel to ensure good bond strength and to avoid hardening of the backing steel due to chromium diffusion from 316L during hot rolling. Due to the relative thin CRA layer it is of great importance to maintain the CRA integrity.

![Figure 2.1 Clad steel pipe](image)

Nominal dimensions for the Norne Satellites clad line pipe are as follows:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal diameter</td>
<td>320mm</td>
</tr>
<tr>
<td>Wall thickness backing steel</td>
<td>21.0mm</td>
</tr>
<tr>
<td>Wall thickness cladding</td>
<td>3.0mm</td>
</tr>
</tbody>
</table>

2.2. Weld configuration

For the Norne project the selected welding consumables were finally chosen to a 309 Mo for root and hot-pass, while the fill layers and capping was performed with Inconel 625. The welding processes chosen were Gas Tungsten Arc Welding (GTAW) and Pulsed Gas Metal Arc Welding (PGMAW). The welding were of various reasons a combination of manual and mechanized welding. Figure 2.2a shows a macro specimen.
The “double jointing” of 12 meter long pipes is performed with equivalent welding process as the later stalk production.

Statoil’s ultimate request was a root pass “without defects”, i.e. the clad integrity should be maintained in the process. The idea behind the GTAW root and hot pass was to avoid possible root defects as much as possible which are time consuming to repair. To maintain an acceptable production rate, mechanized GMAW was chosen for welding of the fill layers. For a pipe with wall thickness of 21+3mm, the weld groove geometry had to be untraditional to allow this untraditional method of filling a groove. The bevel design is given in Fig 2.2b.

![Macro specimen CRA weld](Figure 2.2a)

The amplitude responses in the pulse echo channels, recorded during the actual inspection, have a direct relation with the programmed inspection sensitivity which are derived from artificial calibration reference reflector(s) of which the size and position are dictated by the Inspection Specification(s).

The standard pulse echo registration / presentation is built-up out of the highest amplitude (peak value) and associated transit distance values, recorded in function of the circumferential distance around the weld. Although additional ultrasonic information is available (all ultrasonic information within the programmed gate other than the peak value), this information is not used, not recorded nor presented on the screen. With respect to the inspection of anisotropic weld material, useful ultrasonic information for interpretation of the ultrasonic channel in this way, is lost. Furthermore the standard AUT inspection technique make use of shear wave probes, most appropriate for the detection of weld imperfections within welds of...
Carbon steel having an isotropic material structure, but significant less appropriate when anisotropic material is used.

3.2. CRA AUT inspection & presentation

For the ultrasonic inspection of Austenitic welds and CRA layers, having dissimilar interface(s) and anisotropic material structure, the standard AUT pulse echo presentation is not adequate to present all the essential features required for the correct interpretation of the AUT CRA inspection channels. The CRA inspection technique make’s use of special designed compression wave probes to avoid reflections from the anisotropic welding structure. As illustrated within the Figure 3.2a the compression wave has to pass the primary and coincidence interface between the carbon steel and the austenitic weld material, identified with the green and red borders.

![Figure 3.2a Primary & Coincidence Technique](image)

In order to identify the Primary and Coincidence interface position, the Rotoscan result presentation has been enhanced with an image format being referred to as “All channels mapping” presentation.

The “all-channels mapping” facility within the AUT system software is an essential feature to visualize the inspection result on the screen and to be able to discriminate / evaluate the indications present at the primary and /or coincidence interface within the weld volume to increase the confidence level. With the function “all channel mapping” all ultrasonic wave form information ( A-screen dynamic range 0-200% FSH ) derived from inspection gates, are digitized with a high sampling frequency. Recorded amplitude and corresponding transit distance are converted into a color pattern. In this presentation a coherent display is obtained showing the defect position(s) and geometrical features (e.g. noise out of interface) in relation to the weld centerline.

![Figure 3.2b example of all channels mapping registration.](image)

![Figure 3.2c](image)

* In the left image of Figure 3.2c the data is presented in C-scan image color format. Reference reflectors are visible with their position relative to weld centerline, identified by the white dotted line. During weld examination this image covers the area from Gate start to weld centerline including the Coincidence interface at the other side of the weld body.

* In the right image the standard pulse echo presentation is presented. No weld centre line information is known. This presentation is limited, only the area from Gate start until the weld centre line is covered.

* This C-scan presentation format is essential for the presentation of ultrasonic inspection results out of the Primary and Coincidence interface at the same time.
An additional software feature has been built into the C-scan module to assist in the inspection result interpretation, being the “Averaging Mapping Data” option. This option can be used by the CRA operators to “eliminate” noise out of the digitized ultrasonic image obtained from the anisotropic weld material grain structure, see Figure 3.2d.

![Figure 3.2d](image1)

In the left image the raw data is visible, including “noise”

In the right image the “Averaging Mapping Data” option has been applied.

3.3. Inspection philosophy

3.3.1. General Ultrasonic / Physical aspects

The inspection of austenitic welds having an internal clad layer is difficult and requires extensive qualification of the automatic ultrasonic inspection (AUT) system to be used. Within the Bonga project Snepco (Shell Nigeria) and Acergy (former Stolt Offshore) has spent considerable effort to qualify such a system.

From Ultrasonic / Physics point of view the coarse grain structure of austenitic CRA welds is compared with the fine grained ferritic nature of classic Carbon Steel, see Figure 3.3.1a and 3.3.1b.

![Figure 3.3.1a](image2)

![Figure 3.3.1b](image3)

![Figure 3.3.1c](image4)

The differences in grain size, grain structure and sound velocity between Austenitic and Carbon steel, but also within the Austenitic weld volume itself, have a major impact on the design of the AUT inspection system. At the specified inspection levels, the coarse grain size and anisotropic weld material results in an increased noise level so called “ultrasonic noise”.

This ultrasonic noise is more pronounced for shear waves than for compression waves. It will manifest itself particularly at high sensitivity levels required to reliably defect small weld imperfections within pipeline girth weld inspection.

To avoid this interaction, a low(er) ultrasound frequency can be considered. However, this will have a negative impact on the defect detection and sizing capabilities which will deteriorate with increasing wave lengths.

Secondly sound beam deflection could also play a role in the examination of austenitic welds.

A third aspect is the intrinsic reflection at the interface between the parent and austenitic weld due to small differences in sound speed. Reflection (R) against dissimilar materials (Austenitic weld material – versus Carbon steel), $R = (v_0 - v_1)/(v_0 + v_1)$ and $v_0 = v_1 + \delta v$, see Figure 3.3.1c.
Example:

\[ v_0 = 6000 \text{ m/s} ; \ \delta v = 120 \text{ m/s} \Rightarrow R \approx \frac{1}{2} \times \frac{120}{6000} = 0.01 \text{ (only 1% of a reflection of an ultrasonic wave against a steel to air interface giving a reflection } R=1.00) \]

The coarse grain structure of Austenitic weld & Clad material and/or the unwanted reflections from dissimilar material interfaces, presents itself during ultrasonic examination in an increased noise, reducing the required signal to noise ratio.

Compression waves suffer significantly less from these phenomena than shear waves which inevitable leads to the use of focused angle beam compression and creep wave probes instead of shear wave probes, see Figure 3.3.1d.

The phenomena mentioned above should be considered as “indicative”.

<table>
<thead>
<tr>
<th>Wave mode</th>
<th>Characteristics</th>
<th>Frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear waves</td>
<td>(325m/s)</td>
<td>0.8 mm, 1.6 mm, 0.3 mm</td>
</tr>
<tr>
<td>Compression waves</td>
<td>(5920 m/s)</td>
<td>1.5 mm, 3.0 mm, 0.6 mm</td>
</tr>
</tbody>
</table>

Figure 3.3.1e   Wavelength in view of defect dimension

Not only the ratio of wavelength to grain size causes scattering noise. The grains in the austenitic welds are anisotropic whereby the lattice directions of the individual grains are distributed randomly. The dependency of the sound velocity on the direction of the incoming waves causes a difference in acoustic impedance. This impedance is the cause of this scattering. The difference between the minimum and maximum velocity of shear waves is bigger than for compression waves, hence, shear waves will scatter more than compression waves and this explains the choice to use focused compression transducers for this project.

The effect of scattering on the ultrasonic beam can be demonstrated with the use of numerical simulation software based on finite difference. This modeling approach takes all wave phenomena like mode conversion and scattering effects into account.

In Figure 3.3.1e an overview is given of the wavelengths corresponding to the wave modes (shear /compression) in use in an AUT system: when the grain size of the material under test is becoming in the order of magnitude of the wavelength of the interrogating ultrasonic wave than a significant interaction takes place resulting in an increased noise level \( \Rightarrow \) “material noise”\。“. This disturbing phenomena will happen as a rule of thumb when the largest grain size approach approximately 1/10 the wavelength.

On the other hand the defect detection/ sizing capabilities will deteriorate with increasing wavelength too, as a rule of thumb when the defect size is smaller than 1 to 2 times the wavelength.

In addition reflections will occur between dissimilar materials having slightly different sound speeds. It will manifest itself particularly at high sensitivity levels, as is the case for SCR inspection.

- Top snapshot ;
  Incoming compression/shear wave. A focused compression beam (left) and a focused shear beam (right).

- Middle snapshot ;
  Scattering and intrinsic reflection due to the acoustic impedance.

- Bottom snapshot ;
  The compression wave penetrates the weld, assuring complete volumetric inspection.
3.3.2. Inspection set-up

The inspection set-up for Austenitic welds is similar to the standard inspection configuration set-up for ferritic girth welds in relation to the zone set-up whereby the wall thickness is divided into a number of depth zones.

The used inspection philosophy approach however differs, the selected probes are not related to the weld bevel configuration, as dictated by the applicable standards for AUT on ferritic girth welds, but designed to minimize and/or to exclude that reflections out of the anisotropic weld structure and/or interface are interfering with the inspection result interpretation.

Instead of the traditional shear wave, dual crystal focused compression waves probes are used to enable the full penetration of ultrasonic waves through the weld volume, not hampered by the structure of the involved dissimilar metals and austenitic structure.

The conventional codes (API 1104 19th edition – DnV2000 etc) are based on (ferritic) fine grained Cs steel and assume in the ECA approach that the defect dimensions (height – depth) are known in true physical terms.

The inspection concept of Austenitic welds is based upon a different concept where there is no direct and linear relation between the used calibration reflectors and weld defect dimensions, see Figure 3.3.2 b&c.

In both Figures it is visualized that the weld is inspected from two (2) sides having the gate settings over the entire weld volume, passing the primary and coincidence interfaces. The inspection result of both probes either side of the weld (US & DS) are used for detection and/or confirmation of defect locations, see Figure 3.3.2.d.
Using this technique, the standard approach within AUT techniques to size the weld defects cannot be used, since the detection of flaws are based upon diffraction rather than reflection, see Figure 3.3.2e “Basic mechanisms for response”. The sizing of defects is based upon the information gained out of the total qualification process (relation between amplitude response and defect heights).

3.3.3. Calibration block design

The calibration block for the setting of the inspection sensitivity is different from the standard used for AUT inspection for pipeline girth welds. At first the calibration block is not only made out of an original piece of the actual pipeline, but, in deviation from the standard, also contains an austenitic weld (from the approved welding procedure)

3.3.4. Defect interpretation & interaction interpretation

In order to evaluate whether defects appearing in 2 or 3 adjacent zones in vertical direction/plane are emanating from one and the same defect a comprehensive evaluation of inspection result in relation to possible interaction between the depth zones, is required.
For that purpose the calibration block inspection result, in the All Channels Mapping presentation, is used to explain how the overlap can be identified between the applied depth zones (Z2 through Z7) of a typical Rotoscan CRA inspection result.

In the calibration result presentation it can be seen that adjacent calibration reflectors are recorded and visualized, as it would be the case during actual pipeline inspection circumstances, spaced in circumferential direction and having different depths, see Figure 3.3.4a.

The yellow arrow is pointing at the “main” calibration reflector (Z3 DS) centered in his inspection zone, having the over trace of the adjacent calibration reflectors, present in Z2 and Z4 DS in this case, on both sides. This implicates that during actual CRA weld inspection, defects present in adjacent channels can be also recorded and evaluated to be adjacent and/or independent isolated, depending on transit distances and amplitude response within the gate area. See Figure 3.3.4b illustration of 2 separate defects evaluating the sound path transit distance recordings.

During the qualification phase experience has been gained on the interpretation and evaluation of the CRA inspection results. This experience has been used to train CRA operators to make them familiar with the specific aspects and requirements for the inspection of coarse grained materials.

The training for CRA inspection set-up and result interpretation consist of the following elements:

- Explanation of the differences between the inspection set-up and inspection philosophy for CRA welded welds in comparison with the standard Rotoscan inspection lay-out used for Carbon to Carbon welds.
- Explanation of the different Rotoscan inspection program options required for austenitic girth weld & CRA layer inspection.
- Explanation of inspection data evaluation of CRA inspection result files using the manual interpretation module of the Rotoscan software program.
- Interpretation by the operator under training of “10” selected CRA inspections result files in accordance with supplied CRA acceptance criteria.
- Evaluation of obtained inspection result to assess the competence to evaluate CRA pipeline inspection results.
- The task of CRA protective layers and different types of CRA in use and their inspection implications.
- Typical CRA weld imperfections which may occur in the body and root / hot pass area of the weld and the significant influence of 1G / 2G position on weld bead shape and fusion defects.

In case of successful completion of the test a CRA certificate is formally signed and issued. An example of such CRA certificate is given in Figure 3.3.5.
4. Qualification process

The main objective of the CRA qualification program was to demonstrate that the RTD Automated Ultrasonic Testing system is fulfilling the inspection requirements as outlined in the DNV OS-F101 2000, related to:

- Reliably detect all imperfections in the CRA pipeline girth welds
- To characterize these imperfections as to their nature
- For those imperfections that are potential defects; to determine the circumferential length and through wall heights.
- Fulfill applicable DNV statistical requirements

Earlier gained experience and qualification of the AUT Rotoscan system is used as a reference for the qualification of the CRA inspection system for Norne Satellites project.

The Qualification program was carried out on February 2nd to 4th 2005 and witnessed by the client representatives of TONOR, Statoil and DNV.

4.1. Evaluation of existing CRA qualification data

Investigation and statistical analysis out of referenced CRA qualification data, on similar material as for the Norne Satellite flow lines, has been performed. The data set contained information from 258 defects (94 root, 55 cap and 109 embedded), the majority of this data is based on defects out of the production welds during the offshore campaign. A preliminary statistical POD curve was established, see Figure 4.1.

A comparison is made between the Norne Satellite and the Reference qualification data sets with respect to ultrasonic responses (ultrasonic echo amplitude versus defect height). It has been concluded that data sets were relatively similar, showing similar responses. Due to the fact that results are complimenting each other, the statistical uncertainties of both sets of qualification results, were merged.

4.2. Extent of Norne Satellite qualification work

The following main activities are performed within the Norne Satellite Qualification program:

- Rotoscan system Set-up & Calibration.
- Inspection of 5 welds containing simulated rejectable and acceptable imperfections.
- Evaluation and reporting of AUT inspection results in accordance with the supplied acceptance criteria.
- Evaluation of the Radiographs.
- Comparison of inspection results out of AUT and X-ray.
- Determine positions for macro sectioning.
- Macro result evaluation.
- Analysis and Reporting of results, including comparison and combination with earlier experience and qualification DATA.
Correlation and Conclusion.

4.3. Qualification of CRA Rotoscan system

4.3.1. System Setup & Calibration

The Rotoscan system set-up is carried out in accordance with the inspection philosophy as outlined and described in section 3.0. With all the probes connected into the scanner, each function calibrated on the specified reference reflector, a calibration scan is performed. In Figure 4.3.1 the result of a calibration scan is presented with all relevant calibration reflectors highlighted with the green color per inspection channel.

After each calibration scan an automatic calibration check is performed according to the required limits as per the applicable inspection procedure. In case one or more calibration reflectors is/are not within the limits, the calibration will not be acceptable and the relevant reflector(s) will show up in the red color.

4.3.2. Scanning of welds

After the preparation and calibration activities the scanning of the 5 CRA welds have been scanned in 2 directions from '0' datum point; Clockwise (CW) and Counter Clockwise (CCW), see Figure 4.3.2a. The CCW scans are to prove that the sensitivity settings US and DS are identical and that all imperfections, within tolerances, will be detected with both sides.

All the scans show that we have the same indications as with the original scan but than in the opposite direction, all indications US are now DS and the other way around. Interpretation has been performed on two different threshold levels for both CW and CCW scans;

- Threshold in Cap & Root channels at 20% FSH and Fill channels at 10% FSH.
- Threshold in Cap & Root channels at 40% FSH and Fill channels at 20% FSH.

![Figure 4.3.2a](image)

For the evaluation of the AUT results/ECA calculations the following amplitude to virtual true defect height criteria are used (H is the amplitude % FSH):

<table>
<thead>
<tr>
<th>AUT amplitude H in % FSH</th>
<th>Virtual defect height</th>
</tr>
</thead>
<tbody>
<tr>
<td>H &lt; threshold level (≥20% FSH)</td>
<td>True defect less than 0.6 mm</td>
</tr>
<tr>
<td>20 % (threshold) FSH &lt; H &lt; 80 % FSH</td>
<td>True defect less than 2.2 mm (PE channels)</td>
</tr>
<tr>
<td>H &gt; 80% FSH</td>
<td>True defect equal to zone height, ( Zone Z1 = 2.5 mm, all others Z1 = 3.2 mm )</td>
</tr>
</tbody>
</table>

All defect height mentioned is ”by definition”.

For the conformity in interpretation of the inspection result, the CRA operators are using a decision flowchart. In the flowchart the interpretation is dictated in a step by step approach,
referring to the applicable procedure with sections giving written instructions, see Figure 4.3.2b

**Diagram:**

Decision process for AUT criteria

4.3.3. Reporting of results

After the interpretation of the result, all defect locations are reported into a site report together with all relevant information such as Start and End scan position, location within the weld volume, defect height and whether the defect is acceptable. For example, result presentation see Figure 4.3.2c

After the scan the CRA inspection result is presented on the screen. Its shows the ultrasonic result of the different depth zones in a coherent pattern in function of the pipeline diameter circumference, for a example result presentation see Figure 4.3.2c
given the related acceptance criteria, see Figure 4.3.3

4.3.4. X-ray comparison

TONOR performed comparison X-ray on all 5 qualification welds. The interpretation of the X-ray result has been carried out by TONOR and results were not advised to RTD until after completion of AUT Rotoscan interpretation and macro sectioning, see Figure 4.3.4 for example.

A comparison was made of Rotoscan results with X-ray results including all macro sectioning results. From this comparison it can clearly concluded that AUT has detected more imperfections than X-ray, and so is a more reliable inspection method on these course grained materials.

Also the number of salami sectioning per macro location had been decided during this exercise.

In Figure 4.3.5 all the selected macro locations (excluding extra salami cuts) are highlighted in each specific Rotoscan DATA presentation.

4.3.5. Determination of macro positions

Specific macro locations have been selected in a joint effort by Technip and DNV. The selection was based on the AUT Rotoscan site-report of the CW AUT scan results submitted in February 2005.
5. Qualification results

For the qualification 5 welds with deliberately introduced weld defects were used. Based on the results of the scans, and supplementary radiography, 34 locations were selected by TONOR on the welds for reference destructive testing. For each location in general 3 cross-sections were made 2 mm apart. This revealed in total 41 defects for further analysis, 11 in the root area, 13 in the cap area, and 17 embedded (only defects revealed by 2 or more out of 3 cross-sections, have been included for further analysis). Defect height from the destructive testing has been taken as the average of all measurements made on a defect (the correspondingly calculated standard deviation yields to 0.2 mm). In general, all defects were of small height with an average height of around 1 mm for root and embedded defects, less than 0.5 mm for the cap defects.

A comparison of the ultrasonic responses (ultrasonic echo amplitude versus defect height) from the Norne Satellite and the Reference qualification data showed relatively similar behavior. Due to the fact that results seem to compliment each other, and with the aim to reduce the statistical uncertainties, the both sets of qualification results have been merged.

Taking into account the previous referenced qualification program from the Bonga project, the total number of observations used for evaluation is:

<table>
<thead>
<tr>
<th>Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cap</td>
<td>81</td>
</tr>
<tr>
<td>Embedded</td>
<td>143</td>
</tr>
<tr>
<td>Root</td>
<td>115</td>
</tr>
<tr>
<td>Total</td>
<td>339</td>
</tr>
</tbody>
</table>

All the defect heights as part of the qualification program were of relatively low height, any judgment based on defect heights above 3 - 4 mm (or AUT zone height of 3.6 mm) would have uncertainties, and would have to be based on extrapolation.

DNV OS-F 101 has specific requirements to Probability of Detection (PoD) of defects of non-allowable sizes, as determined by ECA or other approaches followed, to establish defect acceptance criteria, and requirements to uncertainty margins on sizing of defects:

The given condition is: At least a PoD of 90% (to be shown at a 95% confidence level, designated 90%|95%) of detecting relevant defects, and less than 5% probability of under sizing a defect. Because the AUT inspection system, as set up and used for clad pipe austenitic welds, does not really provide height sizing, but uses the echo amplitude information only (via a translation table in combination with length), the PoD 90%|95% requirement has been replaced by a 85%|95% PoR requirement. (Combined requirement Probability of Rejection (Detection and Not under sizing) of a defect of 0.90.95 = 0.85).
The calculated defect height values corresponding to a 85%–95% PoR are given in Figure 5.1.

![Figure 5.1](image)

**Explanation to graphical presentation:**

- Using a Rejection Threshold of 20% FSH, 0.7 mm high root defects will be rejected.
- Using a Rejection Threshold of 20% FSH, 1.3 mm high Cap & Emb defects will be rejected.
- Using a Rejection Threshold of 40% FSH, 2.0 mm high root defects will be rejected.

### 6. Acceptance Criteria

The calculated acceptance criteria based upon the supplied ECA values and established 85%–95% PoR values are converted into a stepwise table.

<table>
<thead>
<tr>
<th>Height [mm]</th>
<th>Echo Amplitude</th>
<th>Max. Length [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2.9</td>
<td>&lt; 32% FSH</td>
<td>&lt; 54% FSH</td>
</tr>
<tr>
<td>2.9 - 3.3</td>
<td>32 - 35% FSH</td>
<td>54 - 60% FSH</td>
</tr>
<tr>
<td>3.3 - 4.0</td>
<td>35 - 40% FSH</td>
<td>60 - 70% FSH</td>
</tr>
<tr>
<td>4.0 - 4.7</td>
<td>40 - 44% FSH</td>
<td>70 - 80% FSH</td>
</tr>
<tr>
<td>4.7 - 5.6</td>
<td>44 - 51% FSH</td>
<td>80 - 94% FSH</td>
</tr>
<tr>
<td>5.6 - 7.7</td>
<td>51 - 65% FSH</td>
<td>94 - 125% FSH</td>
</tr>
<tr>
<td>&gt; 7.7</td>
<td>&gt; 65% FSH</td>
<td>&gt; 125% FSH</td>
</tr>
</tbody>
</table>

In addition to the ECA criteria, special criteria apply to root defects to maintain the corrosion protection provided by the cladding in the root area. This has been taken into account in the acceptance criteria as used in the actual project execution specifying a low recording threshold and adding an extra length limitation provided by Statoil specifications of 50 mm.

### 7. Norne Satellite Clad inspection

In the period March 2005 to end of July 2005, the Norne project has been carried out. In total approximately 788 welds had been successfully inspected using the new developed AUT CRA inspection technique. Acceptance criteria was related to the maximum allowable defects sizes with respect to the reeling process and CRA layer integrity.

Allowable defect sizes were relatively small with respect to the required sensitivity settings and the increased noise level out of the anisotropic austenitic weld and clad structure.
Despite the difficult nature of the welding and inspection a favorable production and repair rate has been obtained.

8. Conclusions

The Rotoscan AUT system as set up and operated by RTD including the acceptance criteria specified has given an adequate fabrication control of the Norne Satellite flow line welds seen in relation to ECA and other criteria implied. Based on the specified 85%-95% rejection criteria and a rejection threshold of 20% FSH, 0.7 mm high root defects and 1.3 mm high cap and embedded defects were rejected.

The key for success was the acknowledgment of the Technip/Statoil project team that the welding configuration, as proposed for the Norne field project was of a different nature and did not allowing the use of standard AUT inspection methods.

Based upon the extensive CRA qualification program carried out, the correct inspection procedures were developed, dealing with all the novelties of the project resulting into a successful project.

9. Referenced documents

References


“Recent experience with the Ultrasonic Examination of different types of Duplex Stainless Steel pipe”, JJM van Nisselroij, in combination with “Semi mechanized ultrasonic inspection of girth welds in Duplex Stainless Steel pipe”, F.H. Dijkstra and A.Otte (RTD) and JJM van Nisselroij (Shell Research Amsterdam NL).


