APPLUS RTD SWAGED WELD INSPECTION PROCEDURE QUALIFICATION

Applus RTD Rotterdam

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Applicable contract(s) governing the provision of this Report:

Objective:

DNV GL has qualified the Applus RTD Swaged Weld AUT scanner system procedure for inspection of swaged weld according to DNVGL-ST-F101, operated according to the procedure No. UT10280, Rev 6.0. The AUT system is based on Olympus Omniscan MX 16/128 Phased Array ultrasonic equipment. The qualification work has been done under agreement between Applus RTD and DNV GL AS, and is in accordance with the requirements as outlined in DNVGL-RP-F118.

Qualification trials included calibration block repeatability trials, elevated temperature trials at 70ºC temperature and reliability trials for sizing accuracy and POD evaluation. In total 8 defective welds were included in the trials, the analysis includes AUT data and information achieved by macro sectioning of 168 independent imperfection observations.

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CONCLUSIVE SUMMARY

The Applus RTD Swaged Weld AUT scanner system procedure has been subject to qualification trials with respect to examination of carbon steel pipe swaged welds according to DNVGL-ST-F101, Appendix D and E. The qualification work has been carried out under agreement between Applus RTD and DNV GL AS, and follows the requirements for AUT qualification of DNVGL-RP-F118.

The qualification trials have covered the inspection of 8 swaged welds in a configuration with a 12" inner pipe with 20.6 mm nominal wall thickness, and a 16" outer pipe of 27.4 mm nominal wall thickness. The actual wall thicknesses were measured to be within the range of 17.9 mm to 22.7 mm for the inner pipe, and within 26.9 mm to 28.5 mm for the outer pipe. Variation in the horizontal width of the weld was measured between 33.6 mm and 42.4 mm. The root gap was found to vary between 1.7 mm and 5.6 mm. Swaging angle varied between 7.6º and 13.9º. The pipe steel grade was X65. The defective welds and corresponding calibration blocks have been subjected to trials for reliability, repeatability and heat influence. In total 168 observations were included in further reliability analysis through obtaining data from macro sectioning results. AUT inspection was performed according to procedure no. UT10280, Rev 6.0 [4. Both activities, scanning and macro sectioning, were witnessed by DNV GL. The naturally occurring imperfection types included in the study have been selected into 5 groups with similar detection characteristics.

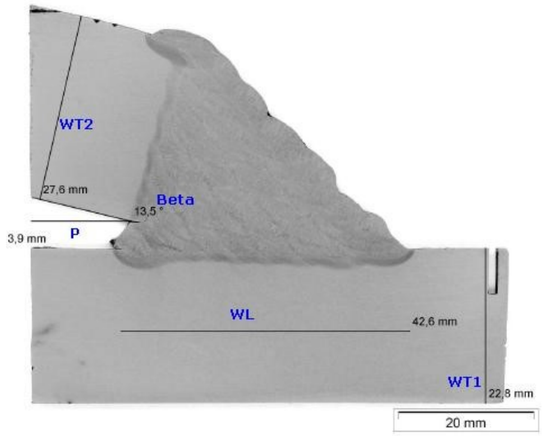

Figure 1: Swaged weld geometry

The Applus RTD Swaged Weld AUT scanner system is based on the Olympus Omniscan MX 16/128 Phased Array ultrasonic equipment. The AUT set-up is designed to provide detection of each type of imperfection by at least two different probes.

Repeatability tests on calibration block shows no deviations more than ± 1 dB in amplitude response from relevant calibration reflectors on repeated scans compared to an initial scan. This falls well within the requirement of ± 2 dB amplitude deviation for repeated scans.

Band offset trials for the probes PA2, PA3 and PA4 shows no significant impact on performance at a band offset of 2 mm, i.e. repeated scans shows all the amplitudes to be within ± 2 dB range. For the probes PA1 and PE5, the ± 2 dB criteria is maintained at a band offset of 1 mm. The detection and sizing capabilities have been found acceptable at operation at an elevated temperature of 70˚C, with deviations in imperfection sizing being to be within ± 1 mm.

The sizing accuracy has been evaluated for each group independently. Sizing analysis results for the imperfection width or height (depending on the position in the weld) are given in the Table 1 below.

Table 1: Imperfection sizing accuracy result summary

	Group 1 (Height)	Group 2 (Width)	Group 3 (Height)	Group 5 (Width)	Group 5 (Height)
5% Probability Under Sizing	-0.6 mm	-1.5 mm	-0.8 mm	-1.0 mm	-0.2 mm
Mean	0.6 mm	-0.1 mm	0.1 mm	0.8 mm	1.1 mm
Standard Dev.	0.76 mm	0.85 mm	0.55 mm	1.06 mm	0.80 mm

In general, a tendency of over-sizing in length is consistently observed. All 7 imperfections were observed with no less than -1 mm under-sizing. Length sizing was performed with the -12 dB drop method, which was concluded to be the most accurate method for length sizing.

Reliable detection at 90% POD with 95% confidence is found within 0.8 mm and 1.0 mm imperfection height or width. Detection performance was based on the data from indications giving signals above noise level. The results for the different groups are given in the Table 2 below.

Table 2: Imperfection size at 90% POD at 95% confidence result summary

	Group 1 (Height)	Group 2 (Width)	Group 3 (Height)	Group 4 & 5 (Width)
90%|95% POD Imperfection Height	0.8 mm	1.0 mm	0.9 mm	0.8 mm

The results are valid for similar configurations, including swaged welds made in carbon steel pipe material, with arc welding without backing rings, without major changes in the AUT system set-up. Variations in swaging and bevel angles, wall thickness, inner and outer pipe diameter, changes in bevel preparation or root gap are not considered major, as long as 100% weld coverage is maintained and the reference reflectors for calibration of the AUT system remains as qualified. The width of the weld should not exceed the active aperture of the PA3 probe.

The effect of modifications in setups has to be evaluated for each case separately. For projects with parameters that differ from this qualification, validity of the results of this full qualification can be confirmed through a limited validation scope, as outlined in [2].

The results presented in this report are suitable to be used as pre-qualification data for further AUT verification, or as complete documentation of AUT performance according to DNVGL-ST-F101 for future Swaged Weld inspection projects. It can be noted that compliance according to DNVGL-ST-F101 ensures compliance with all previous revisions of DNV-OS-F101 which includes requirements to AUT, i.e. the 2000, 2007, 2010, 2012 and 2013 editions.

1 INTRODUCTION

The Applus RTD Swaged Weld AUT scanner system procedure has been subject to qualification trials with respect to examination in general of carbon steel pipe swaged welds according to DNVGL-ST-F101, Appendix D and E. The AUT scanner is based on the Olympus Omniscan MX 16/128 Phased Array ultrasonic equipment. The qualification work has been done under agreement between Applus RTD and DNV GL AS, and follows the requirements for AUT qualification of DNVGL-RP-F118. The purpose for this qualification has been to independently document fitness for use for the system on swaged weld inspection applications. When the qualification trials took place in 2011, the system had not been applied on this application before. The qualification should partly be considered as a technology qualification exercise and allow for rectification of the working AUT procedure during the qualification process. Involved parties in this qualification have been:

Applus RTD – Project owner, all of AUT-activities

DNV GL- 3rd party verification and data analysis

Subsea 7 – Responsible for trial welds (welding by Serimax)

Exova – Destructive testing by macro sectioning

The results presented in this report are suitable to be used as pre-qualification data for further AUT verification, or as complete documentation of AUT performance according to DNVGL-ST-F101 for future Swaged Weld inspection projects.

2 BASIS

The basis for this qualification work has been: DNVGL-ST-F101 [1], Appendix D and E. The qualification has been done following the guidelines and philosophy of DNV RP-F118 [2]. Requirements for AUT qualification given in these documents are mainly dealing with pipeline girth weld inspection, however the methodology and criteria have been found relevant for this Swaged Weld application. Further, the guidance given in the Nordtest Tech Report 394 [3] is followed, as far as applicable. Further details were given on witnessing and guidance during the qualification work.

3 OBJECTIVES

The main objective of the qualification work has been to document the Applus RTD Swaged Weld AUT scanner system performance according to the requirements of DNVGL-ST-F101 [1]. The performance results of the qualification should be directly applicable for relevant application specific acceptance criteria.

According to DNVGL-ST-F101 the basic requirements are:

- A POD of 90% at a 95% confidence level (a 90%|95% POD) has to be documented for a imperfection height smaller or equal to the smallest allowable imperfection height in the group of imperfections in question.
- The 5% limit against under-sizing of vertical imperfection height has to be established
- Uncertainty in length sizing accuracy has to be established.
- Stability at elevated temperature shall be demonstrated
- Consistency in repeated scans of the calibration block shall be documented, both with the scanner mounted on a correctly positioned guidance band, and with band offset.

Beside the requirements of DNVGL-ST-F101, the objective was witnessing of the main qualification activities on site, and to actively participate in the qualification process.

4 ABBREVIATIONS

AUT – Automated Ultrasonic Testing

ECA – Engineering Critical Assessment

EDM – Electrical Discharge Machining

DS – Down Stream

FSH – Full Screen Height

LOP – Lack of Penetration

MLE – Maximum Likelihood Estimation

PA – Phased Array

PE – Pulse Echo

POD – Probability of Detection

SDH – Side Drilled Hole

TOFD – Time of Flight Diffraction

US – Up Stream

UT – Ultrasonic testing

5 DESCRIPTION OF QUALIFICATION PROCESS AND CONTENTS

5.1 Applus RTD Swaged Weld AUT-System Set-up

The Applus RTD Swaged Weld AUT scanner system has been qualified as operated according to a specific AUT procedure that includes a comprehensive description of the system, with document number UT10280 (Rev 6) [4].

The Applus RTD Swaged Weld AUT scanner system is built with basis of the Olympus Omniscan MX 16/128 Phased Array ultrasonic equipment, designed for swaged weld inspection. The swaged welds are the fillet-joints connecting the outer pipe and the inner pipe in the pipe-in-pipe system. In order to achieve full coverage to detect the imperfections possible to occur, the system is combining several ultrasonic techniques. The main inspection is based on 4 phased array (PA) ultrasonic probes, denoted with numbers from PA1 to PA4. The probes PA1, PA2 and PA4 are configured for shear wave sectorial scans in the range of 40°-70°, aimed at planar imperfections normal to the pipe surfaces as illustrated in Figure 2. The PA3 probe is configured for 0 degree lateral (electronic) scanning, longitudinal waves, aimed at planar imperfections parallel to the inner pipe. In addition, detection is reinforced by: One 80° pulse echo probe, denoted PE5, to detect embedded imperfections on the weld bevel face of the outer pipe, and two sets of TOFD probes to ensure detection of inner pipe surface imperfections oriented perpendicular to the inner pipe outer surface. These probes are illustrated in Figure 3.

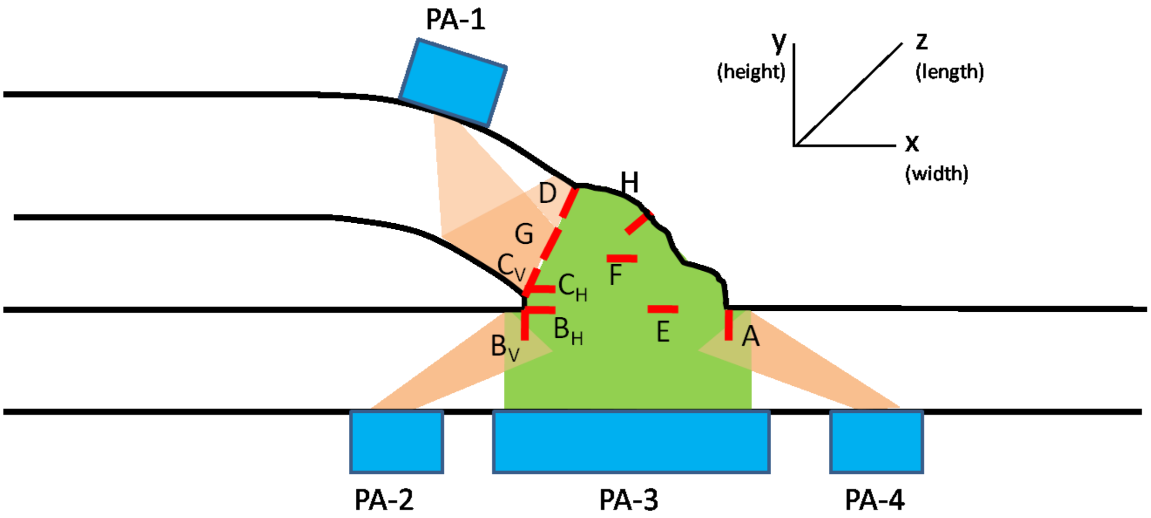

Figure 2: Set-up for Phased Array UT probes PA1 to PA4.

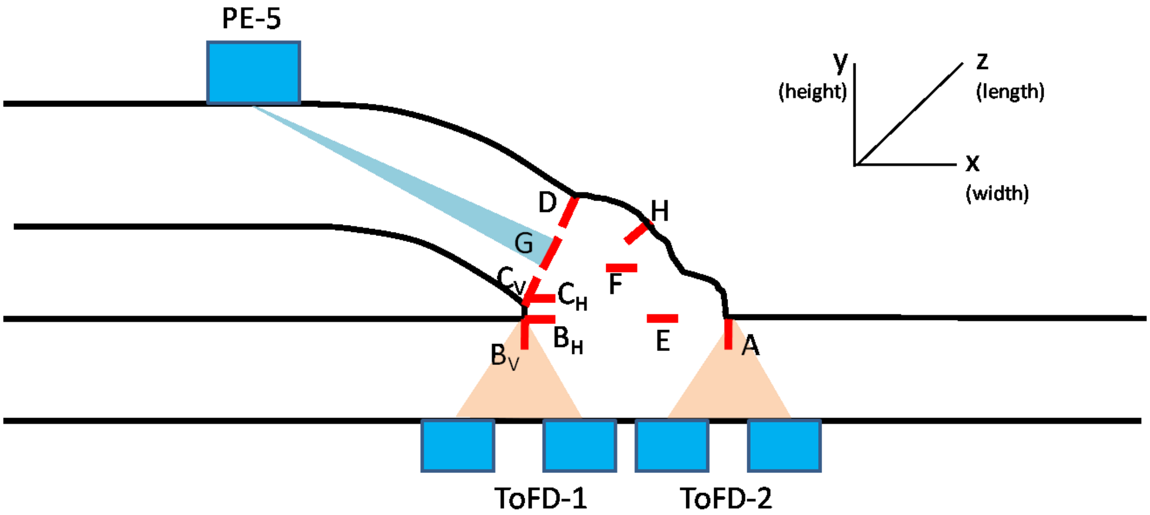

Figure 3: Set-up for probes PE5 and TOFD-1 and TOFD-2

For Figure 2 and Figure 3, imperfection positions denoted with a subscript “V” refers to an expected imperfection orientation vertical to pipe surface, while subscript “H” refers to a horizontal imperfection orientation.

Calibration for the PA and PE probes has been against EDM notches and one side drilled hole (SDH). The dimensions of the different reference reflectors used are given in Table 3. Outer surface PA1 and PE5 are calibrated against EDM notches D and G respectively, with maximum amplitude response set to 80% FSH. Inner surface PAprobes PA2, PA3 and PA4 are all calibrated against SDH E, with maximum amplitude response set to 80% FSH. Detection by TOFD1 and TOFD2 probes are verified by the reflectors Bv and A respectively.

Table 3: Reference Reflector Dimensions

Reflector	Height [mm]	Width [mm]	Length [mm]	Main Probe, Sensitivity
A	2	0.5	20	TOFD2
D	2	1	20	PA1
Bv	2	0.5	30	TOFD1
E	2	1	30	
G	2	1	30	PE5
E (SDH)	Ø3**	-	30	PA2,PA3,PA4

* Reflector E is Ø3 mm SDH

The qualified configuration included a cutback on the inner pipe of 380 mm, which represents the part of the pipe that allows the scanner to be mounted. Corresponding cutback on the outer pipe was 200 mm, which is the distance from the weld fusion face to the coating.

The set-up is designed to provide detection by at least two different probes for each type of imperfection. The main detection method for a imperfection type is denoted as the primary detection, while detection by other methods than the primary is denoted as secondary detection. Concerning AUT reporting during this qualification, all indications above the noise level that were longer than 5 mm and could be confirmed by at least one other probe or probe pair (secondary detection) have been reported. Exception is made for Ch-type of imperfections, which can only be detected by the PA3 probe.

The primary sizing methods at the phased array scans is the -6dB or -3dB drop method from actual imperfection amplitude, depending on which probe that is used for detection, as described in the AUT procedure [4,6]. A slightly modified approach applies for the surface breaking Bh and Ch imperfections, where the reference estimated root position is used at one part of the imperfection for width sizing. TOFD sizing applies for vertical imperfections in the inner pipe (group 3).

The validity of the qualification is in principle dependent on the scanner setup and calibration as described above and in the AUT procedure. The effect of the differences in setups has to be evaluated for each case separately. For projects with parameters that differ from this qualification, validity of the results of this full qualification can be confirmed through a limited validation scope, as outlined in [2].

5.2 Trial welds

The AUT testing was entirely carried out by Applus RTD in Rotterdam and witnessed by DNV GL, and included scanning of in total 9 trial welds with intentionally induced imperfections and 1 corresponding calibration block. 8 of them were subject to macro sectioning. Trial welds were prepared by Serimax, France. The pipe configuration consisted of an inner pipe of 12” (323.8 mm) diameter and 20.6 mm nominal wall thickness, and outer pipe of 16” (406.4 mm) diameter and 27.4 mm nominal wall thickness. The actual wall thicknesses of both pipes varied among the trial welds, for the inner pipe within the range of 17.9 mm to 22.7 mm (WT1, Figure 4), for the outer pipe within 26.9 mm to 28.5 mm (WT2, Figure 4). Further measurements on the 8 macro sectioned trial welds showed a variation in the horizontal width of the weld between 33.6 mm and 42.4 mm (WL, Figure 4). The root gap was found to vary between 1.7 mm and 5.6 mm (P, Figure 4). Swaging angle varied between 7.6º and 13.9º (β, Figure 4). The trial welds steel grade was X65. The number and positions for intentionally induced imperfections were prepared by Subsea 7 and accepted by DNV GL upfront welding. Applus RTD had no involvement in any of the stages in the preparation of the trial welds. Welding was witnessed by Subsea 7 and DNV GL. Natural flaws were induced by running intentionally wrong welding parameters during welding. All the welds were assigned a unique number, from S01 to S09. The weld denoted S02 was used for the repeatability trials, while the weld denoted S03 was used for the temperature trials. The welds with numbers from S01 to S08 were used for reliability trials.

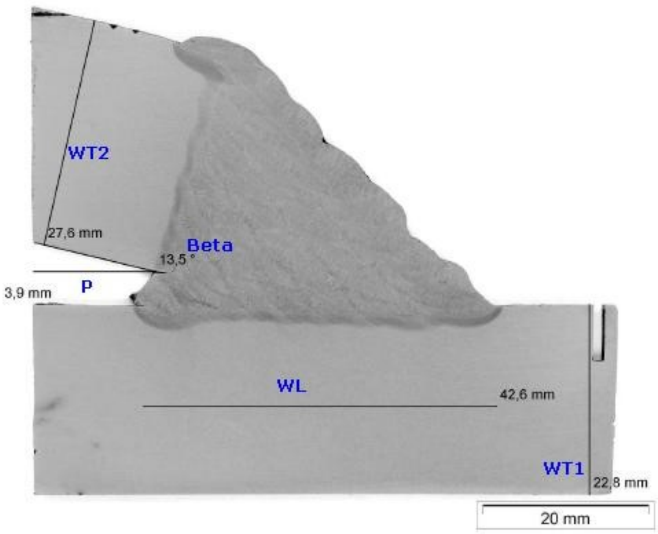

Figure 4: Description of dimensions of the swaged weld

Trial welds and calibration blocks were AUT scanned in 5G position (horizontally).

Positions for macro sectioning were marked up on the weld using the AUT scanner, to recognise the precise position. For all type of imperfections, at least 5 salami slices were done for each macro section position. For most of the welds, salami slices were done at 2 mm distance between each macro at each macro position, but for three of the welds (S03, S04 and S07) this distance was 2.5 mm. For each of the welds, all imperfections chosen for macro sectioning have been given sequential ID-numbers, like M01. These imperfections are also attributed to a macro position, which is given in mm from the defined scanning start point.

Weld macro cross sections were prepared and measured by Exova [7-14]. Prior to macro sectioning, the ID-number for the macro and the position for each macro section were hard stamped in the material at US side close to the weld. Section slices were cut, ground with grinding paper in steps down to P1200 grit and etched with 10% Nital, before they were photographed.

Upon evaluation of macro sections, there was some uncertainty found in the mark up position of the maximum imperfection height/width detected by probes on the inner pipe, i.e. PA3. This uncertainty was identified to be attributed to the transferring of macro section positions identified at the inner pipe to mark up at the outer pipe. Any uncertainty has been compensated for by adding more macro sections for each position, and by careful interpretation of all macros compared to the AUT scans. The efforts put into the actions to compensate for the initial uncertainty are confirmed to be sufficient to achieve analysis results representative for the system performance. For future qualification or validation activities, it is recommended to improve the method for mark up of macro section positions, to avoid this problem.

The length sizing accuracy analysis has been strengthened with 2 observations from a different project with similar weld configuration (historical data). This pipe configuration consisted of an inner pipe of 8" outer diameter and 22.2 mm nominal wall thickness, and outer pipe of 11" diameter and 17.5 mm nominal wall thickness.

A compilation of the qualification data can be found in the appendices.

5.3 Imperfections

In total 9 different types of possible welding imperfections to be covered by the inspection were identified by Applus RTD and Subsea 7 during development of the Swaged Weld AUT scanner. These imperfections are illustrated in Figure 2. In order to rationalise the qualification process, the imperfection types of same or similar detection characteristics were combined into 5 groups. The imperfections within each group were treated as identical during analysis. The principle of having at least 29 independent observations within each group, as outlined in DNVGL-RP-F118 [2], has been followed.

Macro section locations were selected in order to assure sufficient data from the initial imperfection groups, as defined in the agreed scope of work [5]. Some re-arrangements were done for the imperfection groups 1,2,4 and 5 upon evaluation of macro sections, due to the observed imperfection geometries and the improved understanding of detection after the initial analysis. All re-arrangements were agreed amongst DNV GL, Applus RTD and Subsea 7. The re-arrangements were as follows: G-imperfections were included in group 1, as the response from PA1 was found to correspond well to D-imperfections. This was partly motivated by the fact that most of the C-imperfections were of a horizontal type with main detection by PA3, and would therefore not fit into this group. The C-imperfection type were split into two types, C- vertical (Cv) with the intended orientation along the weld bevel, and C-horizontal (Ch) parallel to Bh-imperfections but at a higher depth. Cv imperfections were still included in group 1, while Ch imperfections were included in a new group together with Bh imperfections denoted group 2. It turned out that most of the intended C-imperfections were actually Ch, and only a few imperfections were of the Cv-type. It was decided to evaluate the PA3 detected Ch and Bh imperfections separately from E, F and H imperfections due to the increased criticality for the surface breaking imperfections close to the inner pipe, and the slightly different sizing technique used. F and H imperfections were originally grouped based on orientation relative to the inner pipe surface. Upon macro sectioning, it was clear that the shape of most of the F and H imperfections could not directly be attributed to a certain orientation and usually seem to follow the weld passes. A distinction on orientation as originally proposed is therefore not regarded as relevant. Instead, F and H imperfections have been evaluated on width and height sizing independently. The imperfection groups and number of observations applied for the analysis are summarised in Table 4.

Table 4: Imperfection Groups for Data Analysis				
Group	**Imperfection type**	**Primary Detection**	**Comment**	**# Observations**
1	Cv D G	PA1 PA1 PA1	PA3 secondary detection, PA3 secondary detection, PE5 secondary detection	1 14 21
2	Ch, Bh	PA3		21 Ch,14 Bh
3	Bv A	TOFD-1 TOFD-2	PA2 secondary detection PA4 secondary detection	17 15
4	E, F, H (Width)	PA3	PA1, PA2 & PA4 secondary detection	8 E, 26 F, 11 H
5	F, H (Height)	PA1, PA2 & PA4	Sizing is performed by the secondary detection probes, as PA3 is primary.	16 F, 3 H

The numbers of independent observations for the different groups are: 36 from group 1, 35 from group 2, 33 from group 3, 45 from group 4 and 19 from group 5. In total 168 independent observations. The number of independent imperfections evaluated is somewhat lower, mainly due to that the same F and H imperfections appears in both group 4 and 5.

The distinction between group 4 and 5 might need a further elaboration. The Applus RTD Swaged Weld AUT scanner system is not designed for reliable height sizing of imperfection types E, F and H, as the 0º PA3 is the primary detection probe for all these imperfections. Qualification data confirmed that all E, F and H imperfections included in group 5 were detected by the PA3 probe. It was further possible to measure the vertical height of some of the F and H imperfections using additional information for sizing from the secondary PA2 and PA4 probes. Since the imperfections of group 5 are evaluated by information from the secondary detection probes, sizing accuracy results are presented for information only. Regarding the detection performance evaluation (POD), the distinction of E, F and H imperfections in two groups is regarded as irrelevant, and they are evaluated as one group. In total 45 independent observations of group 4 and group 5 imperfections have been included in the POD analysis.

Not all of the observations provided in Table 4 above have been included in the analysis. Disregarded indications with low amplitude responses have been included in the POD analysis, but not included in the height sizing accuracy analysis due to the lack of sizing in line with the procedure. The affected indications are 5-17, 8-14, 2-19, 7-19 and 1-16. Therefore, the numbers of observations in the height sizing analysis are a bit lower than in the POD analysis (i.e. 1 disregarded observation each in groups 1 to 5). In addition, 1 observation of A-type (7-19, group 3) and 3 observations of H type (2-3, 4-11, 7-15, group 4 and 5) have been disregarded from analysis due to unlikely defect geometry. In all these cases it has been considered that the weld cap geometry signal disturbs the imperfection UT response in a way that is irrelevant for the imperfection type that is inspected for.

3 observations for the length sizing accuracy evaluation have been disregarded from the analysis, based on doubt in correct mark-up for macro sectioning. This applies to observations 6-7, 5-6 and 5-17.

5.4 Extent of Qualification Activities and DNV GL Witnessing

The extent of qualification activities was agreed upon upfront qualification, in accordance with DNVGL-ST-F101. The following activities has been performed by Applus RTD, and witnessed by DNV GL:

- Repeatability scans on calibration block, 10 consecutive scans without band removal.
- Guidance band offset scans on calibration block 3 scans each with a band offset of +1 mm and -1 mm, and 2 scans each with band offset of +2 mm and –2 mm. The band was moved with the scanner still attached to the band.
- Temperature trials, 6 consecutive scans of one defective trial weld heated to 70ºC. Before and after each scan, one scan on calibration block kept at ambient temperature.
- Capability scanning of 9 defective welds.
- Interpretation of AUT scans.
- Selection of macro section positions based on official interpretation of AUT scans of 8 defective welds.

In addition, macro sectioning activities at Exova, Spijkenisse, has been partly witnessed by DNV GL.

5.5 Analysis Extent

5.5.1 Repeatability and Temperature Trials

DNVGL-ST-F101 requires a verification scan series of one calibration block reference scan, where the amplitude deviations in any channel over 10 consecutive scans shall be within ±2 dB. Fulfilment of this requirement indicates acceptable repeatability performance of the system. In addition, 3 scans shall be performed with band offset 1 mm each to the DS side and to the US side. The results from the repeatability trials are found in paragraph 6.2.

Furthermore, DNVGL-ST-F101 requires temperature sensitivity trials. Temperature sensitivity trials are performed to guarantee that the inspection performance are not influenced by a large difference in temperature between the calibration block and the weld. No specific requirements are given for the implementation of the temperature trials in DNVGL-ST-F101 [1]. However, such requirements are given in DNVGL-RP-F118 for girth weld AUT scanner qualification [2], which includes series of 15 scans at elevated temperature. For this Applus RTD Swaged Weld AUT scanner system qualification, the methodology for girth weld scanner qualification was considered as inconvenient to implement, due to the long time needed to mount and dismount the scanner, and the slow scanning speed. Instead, a series of 6 consecutive scans of the same weld, heated to at least 70 ºC before each scan, was considered as practically feasible and relevant to the use in field. Before and after each scan, one scan on the calibration block kept at ambient temperature should be done (cal in-cal out). The time period between the start of scanning of two consecutive scans is denoted one cycle, and includes time used for scanning of one weld, mounting scanner off the weld and onto the calibration block, achieving acceptable calibration scan, mounting scanner back on the weld and in between; heating the weld to 70 ºC. Five imperfections, one for each probe of primary detection, have been selected for performance evaluation, i.e. deviations in height sizing upon elevated temperature. Concerning the interpretation of the data result, deviations in height sizing for selected imperfections shall not exceed the sizing tolerances estimated upon the qualification analysis. Concerning the imperfection of G-type, only deviations in amplitude has been evaluated since detection by this imperfection type is done by the conventional probe PE-5. The amplitude deviations shall be within ±2 dB, as with the calibration block repeatability trials. The results of the temperature trials can be found in paragraph 6.3.

5.5.2 Probability of Detection Reliability Trials

Probability of Detection (POD) analysis has been performed to comply with the requirements in DNV-OS-F101. The main purpose of a POD analysis is to document reliable detection of critical imperfection heights, for instance as derived by ECA for project specific acceptance criteria. The imperfection height at 90% POD at the 95% confidence level is regarded as the reliably detected imperfection height by the AUT system. The method applied for the present POD-analysis is described in the Nordtest technical report 394 [3], and is based on the MLE method where so called hit-miss AUT detection data are fitted to a statistical model. The statistical model used in the analysis was the one recommended in the Nordtest document [3]:

$$P(x, x_0, b) = 1 - \frac{1}{1 + \left(\frac{x}{x_0}\right)^b}$$

For the expression above, x is the imperfection dimension (e.g. height or width), and x_0 and b are the model parameters to be fit to the trial data. Hit-miss refers to the outcome of inspection of a imperfection with a certain size by the AUT system, the imperfection is either detected (hit) or not detected (miss). For instance a "hit" might corresponds to a imperfection with a signal response clearly resolved and reported by the AUT equipment, while a "miss" corresponds to imperfections giving no or less clear signal response. For TOFD detection, a hit would typically be when a imperfection gives a defined signal at the scan, while a miss would be the opposite case. The Applus RTD Swaged Weld AUT scanner system set-up is designed to detect each imperfection type with at least two methods, however a imperfection will be denoted as detected, or "hit", regardless of being detected by the primary or secondary method. For the present POD analysis, both hit and missed imperfections are attributed to a imperfection height which is the reference imperfection height as measured at macro sections. The statistical model allows POD to be evaluated as a function of the imperfection height, and presented as a curve. 90% POD at 50% confidence refers to the actual fit between the collected hit-miss data and the statistical model used. The 95% confidence interval includes the uncertainty referred to the amount of collected data and how well the data fits to the estimated POD. A larger amount of data together with a closer fit to the model will give a confidence band closer to the estimated POD-curve. There is usually a considerable amount of conservatism in the detectability requirement of 90% POD at 95% confidence level for the smallest acceptable imperfection height.

How the term "detection" is interpreted for this probability of detection analysis might need a further clarification. Depending on the application, "detection" in such analysis can refer to imperfections actually reported by the AUT operator, imperfections with amplitude responses below applied reporting threshold or all imperfections with a signal response possible to resolve at inspection. For the present PAscans, all indications with ultrasonic signal response above the noise level have been taken into account. A reasonable approach for detection performance evaluation might be by evaluating the imperfection detection ability through the reports by the AUT operator, as interpretation is regarded to be a main factor when it comes to actual performance in field operation. Such evaluation will give an estimate for the probability of disregarding imperfections. For the present study, it was chosen to evaluate imperfections fully missed by the system calibrated as per the AUT procedure. The reason for this approach is that the Applus RTD Swaged Weld AUT scanner system is a recently developed system without previous experience available. As a consequence, the results from POD analysis presented in this report will represent estimates for the performance of the system with the amplitude reporting threshold at the noise level. The results assume careful interpretation by the operator. Due to this, some imperfections, being not reported by the AUT operators but giving indications on the scans, are included in this analysis as "detected" (or "hit"). It should be further noted that the defective welds had a large number of imperfection indications. It is anticipated that production welds would be much cleaner and thereby it might be easier to spot single indications by the operators.

5.5.3 Imperfection Height Sizing Accuracy

For the Applus RTD Swaged Weld AUT scanner system, imperfection height sizing is in general performed by the information from the primary detection probes. Only for cases where the imperfection is not properly detected by the primary detection method, the secondary detection probe is used for height sizing.

In DNV-OS-F101, height sizing accuracy is attributed to the project specific acceptance criteria. It is specified that the AUT system shall show reliable detection of the smallest "allowable" imperfections according to the acceptance criteria with less than 5% probability of under-sizing. Evaluation of imperfection height sizing accuracy is done by a comparison between the imperfection height as measured by AUT and the reference imperfection height measured on macro sections. The macro section with the highest measured indication will be used as the reference when there are more than 1 macro sections made at one imperfection position. Sizing inaccuracy is defined as the reference imperfection height from the macro subtracted from the AUT measured imperfection height. A negative sizing inaccuracy will then indicate under sizing. The sizing inaccuracy is assumed to be normally distributed, and the 5% probability should in principle be found from the normal distribution. In cases where the sizing data does clearly not follow normal distribution, the observed 5% percentile might be used instead.

5.5.4 Imperfection Length Sizing Accuracy

Imperfection length sizing accuracy shall in principle be evaluated by the same methodology as for height sizing accuracy, as described in paragraph 5.5.3. Reference imperfection length will be evaluated by macro sectioning at the ends of the imperfection. The position of the last macro sections before a clean macro at both ends containing an indication from the imperfection will determine the reference length by macros. Any indications of the imperfection, regardless of size, will be used for length sizing.

For the present study, the number of observations is too low for a proper statistical analysis.

5.5.5 POD and Height Sizing Accuracy in Use

Both POD and height sizing accuracy are intended to be used in connection with project specific acceptance criteria, usually derived by ECA.

The POD is a statistical description of the AUT system's ability to reliably detect a flaw of a certain size. The purpose of a POD evaluation is to document that the AUT system is capable to reliably detect the imperfections of critical sizes according to applicable acceptance criteria with applied rejection thresholds. The important parameter, in this context, is that the imperfection height at 90% POD at 95% confidence level, which is compared with the smallest allowable (ECA) imperfection size.

The purpose of the height sizing accuracy value, under sizing allowance, is to adjust the ECA derived imperfection sizes of the acceptance criteria to assure that all flaws exceeding the smallest ECA allowable flaw is rejected. For instance, if the smallest allowable ECA imperfection size is 1.0 mm and the under sizing allowance is 0.3 mm, the smallest allowable imperfection size at AUT inspection has to be 1.0mm-0.3mm = 0.7 mm. When it comes to POD, the AUT system is qualified for use as long as the 90%|95% POD imperfection height is below 1.0 mm, which is the smallest allowable ECA imperfection size.

6 RESULTS

6.1 Analysis prerequisites

DNV GL has witnessed official scanning for the repeatability, reliability and temperature trials. DNV GL was further involved in the selection of macro section positions, and has witnessed some parts of the macro sectioning activities.

6.2 Repeatability

The pre-examination repeatability test scans on calibration blocks show consistency for repeated scans. Each of the 5 probes in the set-up shows no deviation more than ±2 dB from the reference level of 80% FSH. In general, 10 consecutive scans on the calibration give deviation within ±1 dB, as illustrated in Figure 5. The results of the trials confirm that an offset of 1 mm for the band do not affect the performance of the system. The results of the test can be found in Appendix A.

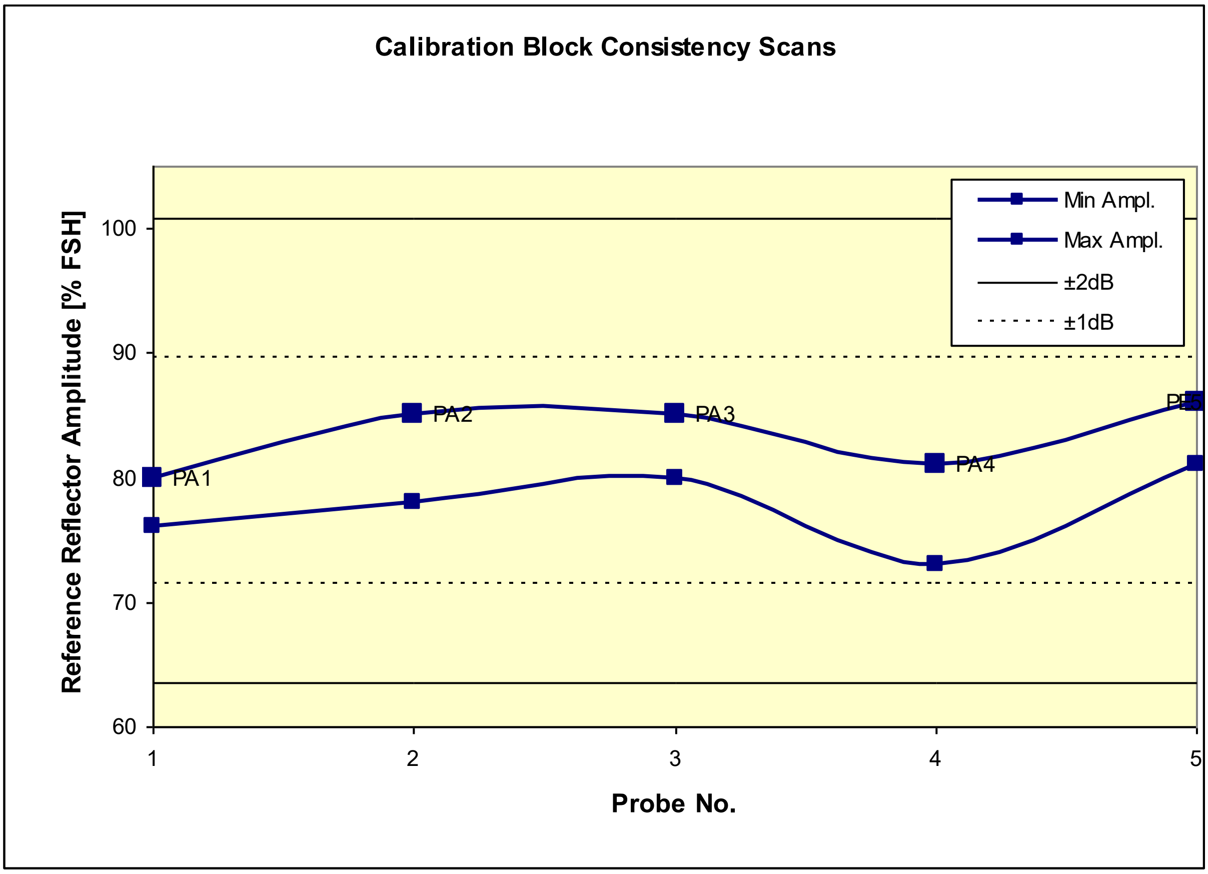

Figure 5: Repeatability trial results. Maximum and minimum amplitude for the reference reflector reported within 10 scans on the calibration block is shown.

Consistency performance with the band offset at ±1 mm and ±2 mm from scribe line was evaluated by carrying out 3 scans at each offset on the calibration block. The scanner was fixed to the band during the entire offset trials, to maintain comparable results. The results show some deviations from the scan at no offset, at least for the Probes for sectorial scans and the PE5-probe. For a band offset of ±1 mm, all amplitudes are reported within ±2 dB from a reference level set at 80% FSH. For a band offset of ±2 mm, amplitudes for all probes except for PA1 were reported within ±2 dB. PA1 shows some large amplitude variations at ±2 mm band offset, which is assumed to be attributed to the geometry of the pipe in combination to the long beam path and the skip. However, the impact of this result is regarded to be limited on the height sizing accuracy, as height sizing is not amplitude dependent but based on the -6dB drop method. Furthermore, secondary detection for the D-imperfection type attributed to calibration of PA1 is by the PA3 probe, which has proved consistent results at the ±2 mm offset.

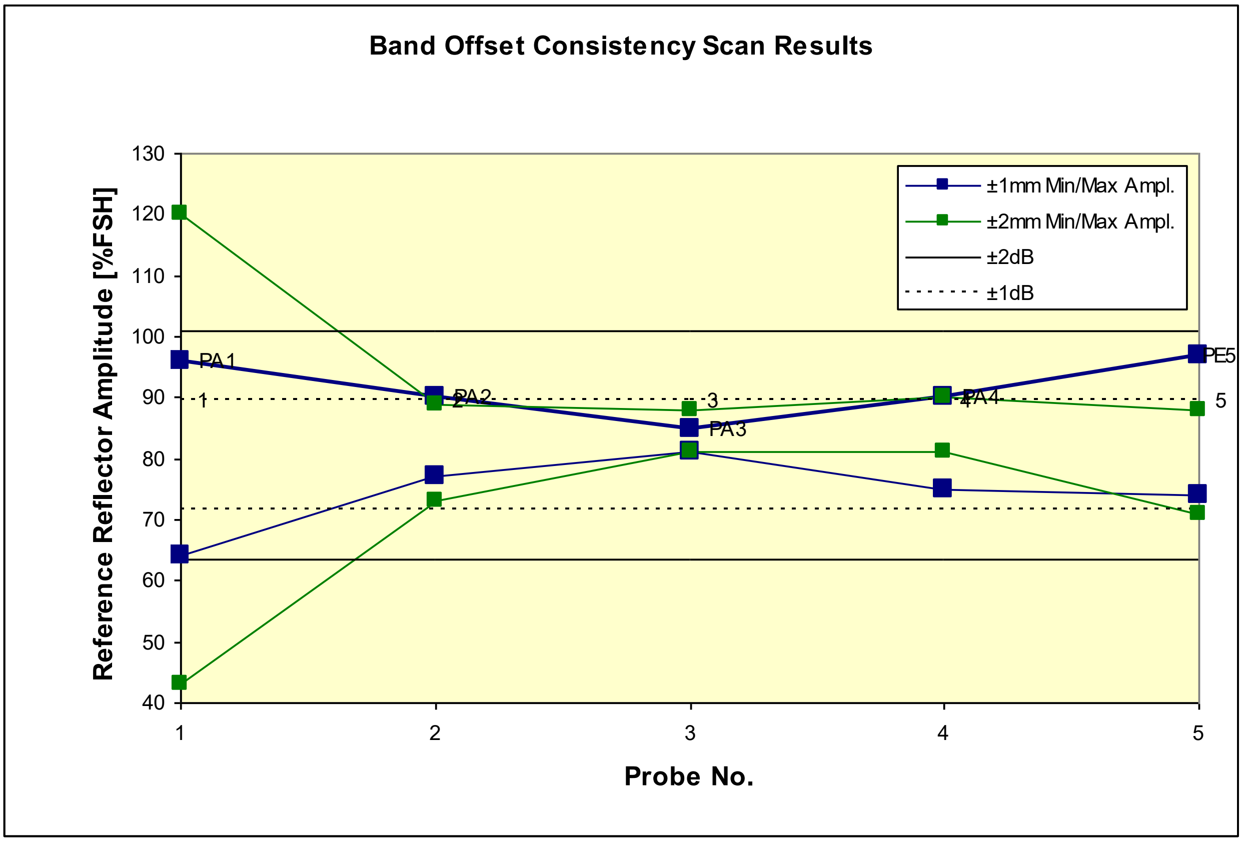

Figure 6: Calibration block repeatability results with guidance band offset of ±1 mm and ±2 mm.

To sum up the band offset scan results, the probes PA2, PA3 and PA4 mounted at the inner surface are found to perform stable at band offsets of ± 2 mm. For the probes mounted at the outer surface, PA1 and PE5, stable performance is demonstrated for band offsets of ± 1 mm.

6.3 Temperature Sensitivity

The high temperature test scans shows good consistency between scans at ambient temperature and scans at elevated temperature. In total 5 imperfections, one from each of the imperfection groups, all with different probes as primary detection, were investigated. In addition, 10 consecutive scans at ambient temperature were performed for comparison. The results are illustrated in Figure 7, which includes measurements of maximum height or width of 4 of the imperfections in the trial weld at an initial elevated temperature of at least 70°C. The figure shows the maximum and minimum imperfection height/width measured within the 6 scans at elevated temperature performed, the corresponding results at ambient scans, and tolerances for deviations of ±1 mm from the average dimension measurements at the ambient scans. Concerning the last imperfection evaluated, this was of the G-type, primarily detected by the PE5 probe. Only maximum amplitude signal was reported for this imperfection, which is related to the imperfection height for this particular probe set-up. The deviations in maximum amplitude were found to be within ±2dB from ambient average amplitude for all scans at elevated temperature.

For the other 4 imperfections, dimensions in terms of height or width were considered to give the most relevant information about the consistency at elevated temperature, since the maximum %FSH amplitude is not directly attributed to the measured imperfection dimensions. The elevated temperature was seen to cause some more deviations in measured imperfection height/width than seen at ambient condition. All of these measurements at the elevated temperature were found well within ±1 mm from the corresponding measurements at ambient conditions.

The cycle time was for most of the cycles kept between 30-40 minutes. The conditions used are regarded as representative to the conditions at field inspections.

Heating was performed by gas heaters, and the temperatures were measured with an infrared thermometer in the root area.

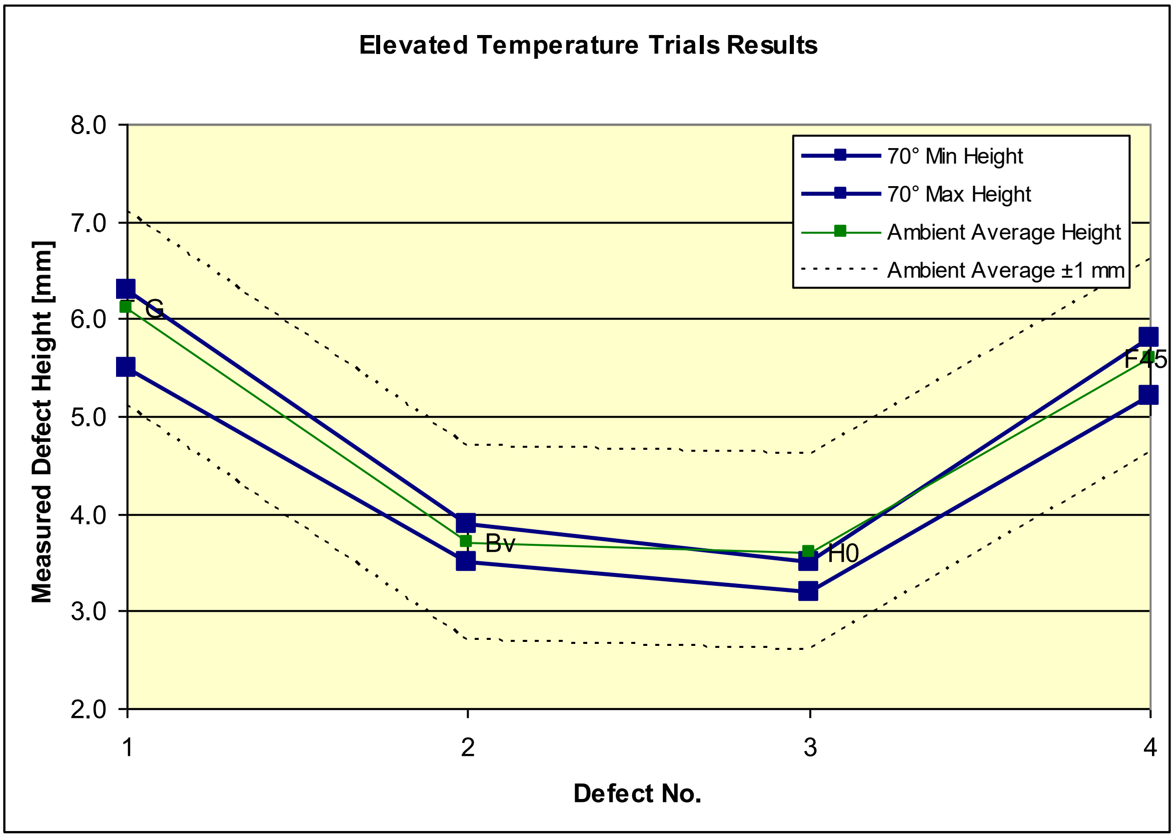

Figure 7: Elevated temperature repeatability and ambient scan for imperfections. Imperfection types: 1: G, 2: Bv, 3: H0, 4: F45

6.4 Vertical and Horizontal Imperfection Sizing Accuracy

6.4.1 General

Vertical and horizontal sizing accuracy has been evaluated for the five groups separately. Accuracy has been evaluated for only one dimension for each group, either vertical imperfection height or horizontal imperfection width. The relevant dimension (width or height) for the different groups is determined by the natural orientation and geometry for the different imperfections and by the most relevant dimension at the normal imperfection position in terms of criticality. The imperfections belonging to each of the five groups are illustrated in Figure 8.

As described in paragraph 5.3, only imperfections with height sizing are included in the analysis and therefore the number of observations differs from the number of observations included in the POD analysis.

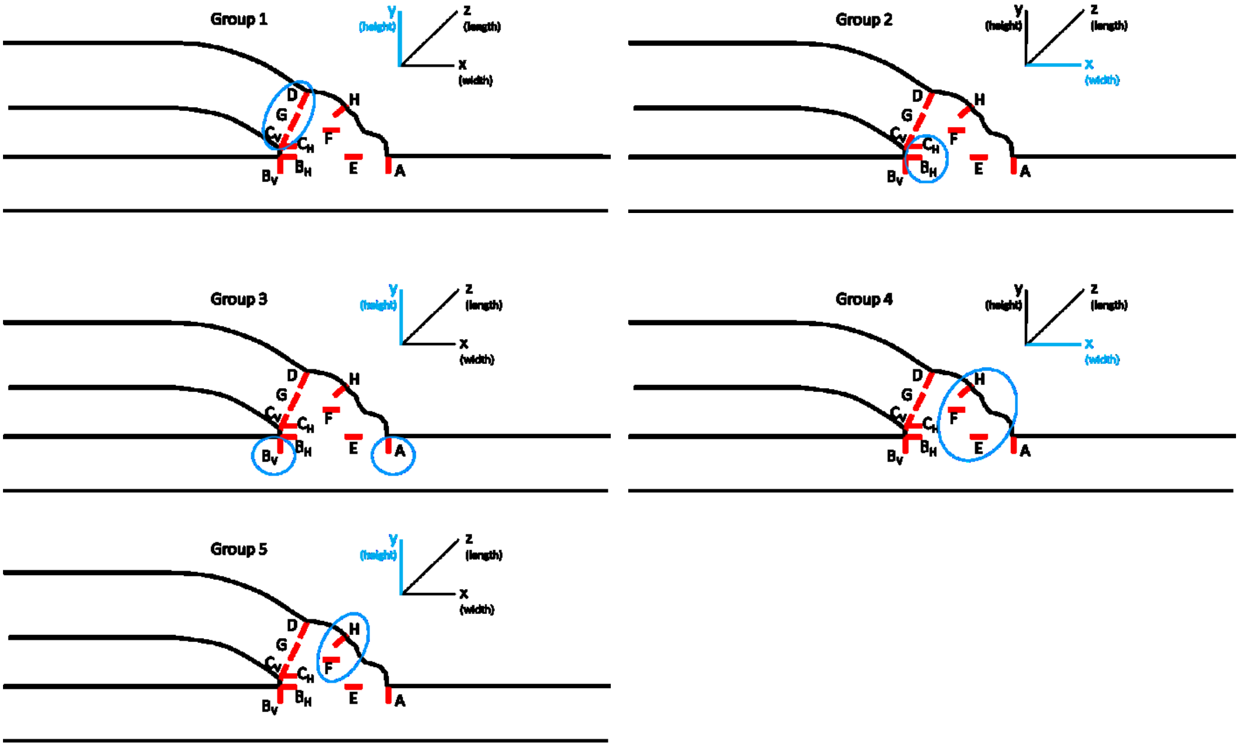

Figure 8: Imperfections with orientations attributed to the five different imperfection groups

6.4.2 Vertical Height Sizing Accuracy Group 1: Cv, G and D Imperfections

The data from group 1 consist mainly of observations from G and D imperfection types. The height sizing for this group is performed by the PA1 scan. The embedded G-imperfection shows a slight tendency to be more over-sized than the surface breaking D-imperfections, which act as corner traps. In total 35 imperfection observations have been included in the width sizing evaluation for this group, including 1 Cv-imperfection, 20 G-imperfections and 14 D-imperfections.

The mean over sizing of this group as a unit is 0.64 mm, with a standard deviation of 0.76 mm. It has been estimated a less than 5% probability to under size group 1 imperfections more than -0.61 mm, as illustrated in Figure 9.

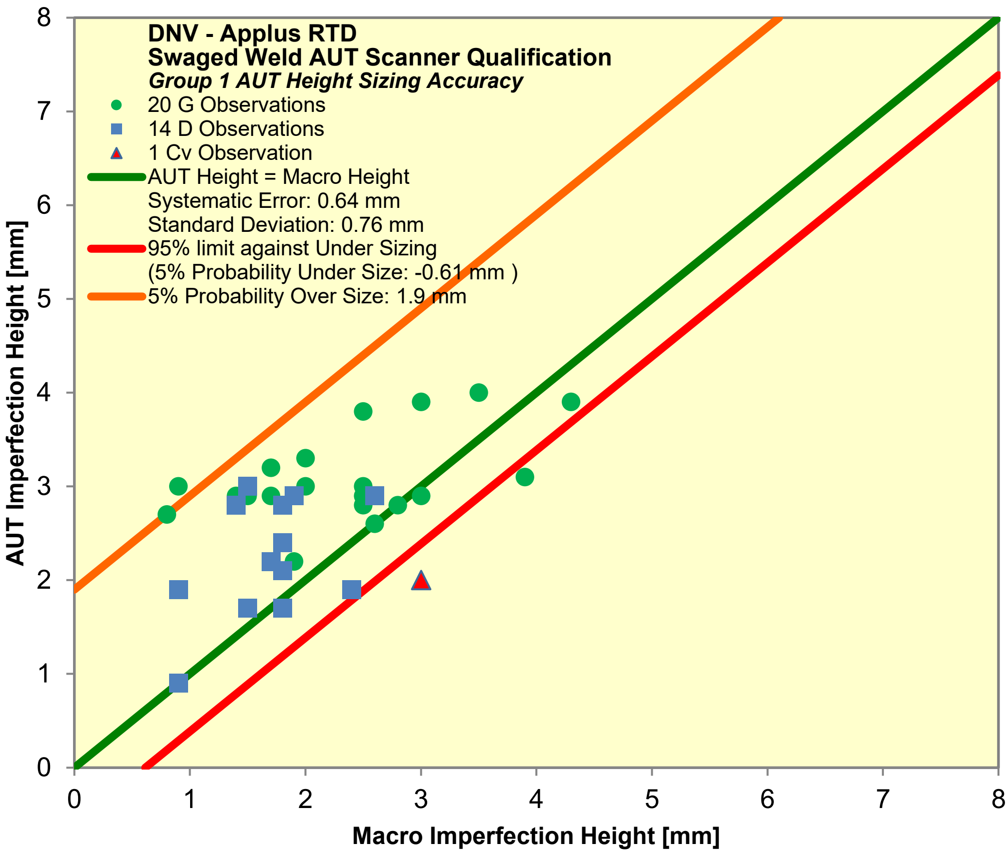

Figure 9: Vertical height sizing accuracy plot of group 1 observations: G, D and Cv imperfections.

6.4.3 Horizontal Width Sizing Accuracy Group 2: Bh and Ch Imperfections

In total 34 imperfection observations have been included in the width sizing evaluation for group 2, including 21 Ch-imperfections, and 13 Bh-imperfections.

It was observed one case where excessive root penetration and a sort of lack of penetration (LOP) disturbed the interpretation of a Ch imperfection width. At this occasion the geometry of the reflecting surface at the LOP caused the imperfection to appear as a non-surface breaking imperfection.

The mean under sizing of the group 2 as a unit is -0.12 mm, with a standard deviation of 0.85 mm. It has been estimated a less than 5% probability to under size group 2 imperfections more than -1.52 mm, as illustrated in Figure 10.

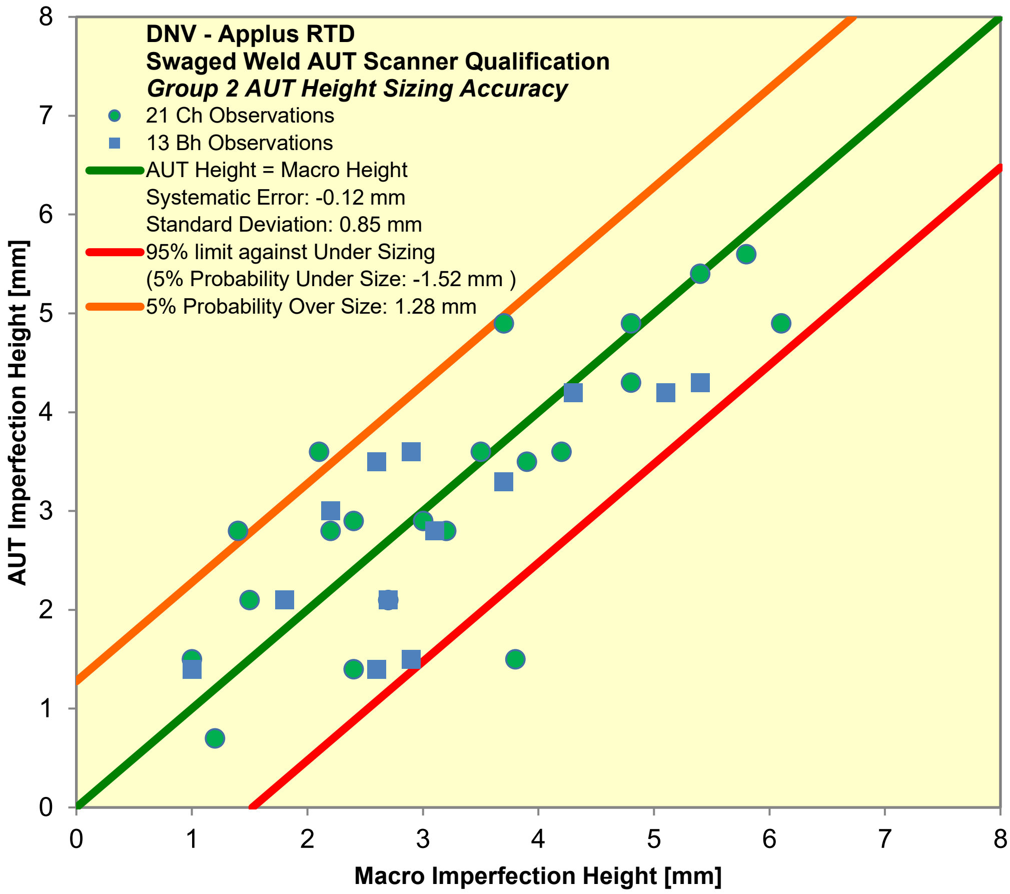

Figure 10: Horizontal width sizing accuracy plot of group 2 observations: Ch and Bh imperfections.

6.4.4 Vertical height Sizing Accuracy Group 3: Bv and A Imperfections

In total 31 imperfection observations have been included in the width sizing evaluation for group 3, including 17 Bv-imperfections and 14 A-imperfections.

The mean over sizing of this group as a unit is 0.10 mm, the standard deviation of the sizing inaccuracy is found at 0.55 mm. It has been estimated a less than 5% probability to under size group 3 imperfections more than -0.81 mm, as illustrated in Figure 11.

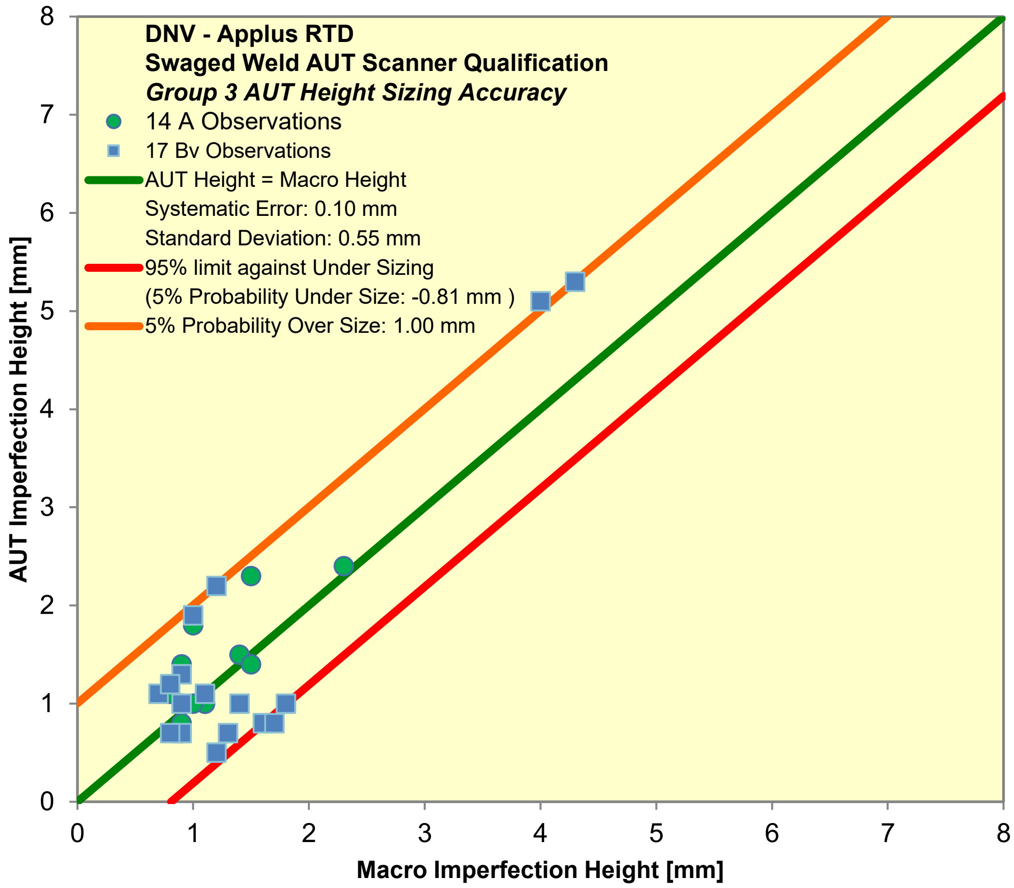

Figure 11: Vertical height sizing accuracy plot of group 3 observations: Bv and A imperfections.

6.4.5 Horizontal Width Sizing Accuracy Group 4: E, F and H Imperfections

In total 41 imperfection observations have been included in the width sizing evaluation for group 4, including 8 E-imperfections, 25 F-imperfections and 8 H-imperfections.

A difference in detection and sizing was observed between the surface breaking H-imperfections and the embedded types. AUT response from H-imperfections is dependent on cap geometry in addition to the imperfection itself, as the imperfections acts as a sort of extension to the cap geometry and might create corner traps. Horizontal sizing is therefore observed to be less accurate for the H-imperfections than for the E and F types.

Concerning the embedded imperfections, E imperfection sizing is apparently more precise than for F imperfections, as the orientation of the imperfections is fixed in the plane 90° to the sound beam. Some over sizing was seen for E-imperfections.

F-imperfection width sizing accuracy was observed to be imperfection geometry dependent, which cause more sizing uncertainty for this imperfection type than seen for plane imperfection types. Usually, F-imperfections were observed to have curved geometries with rounded edges, often following the weld passes. In general, over sizing is seen for the F-imperfections, but a couple of imperfections under sized due to imperfection geometry unfavourable for ultrasonic response are observed.

A mean over sizing of 0.79 mm is found in this group as a unit, the standard deviation of the sizing inaccuracy is found at 1.06 mm. It has been estimated a less than 5% probability to under size group 1 imperfections more than -0.95 mm, as illustrated in Figure 12.

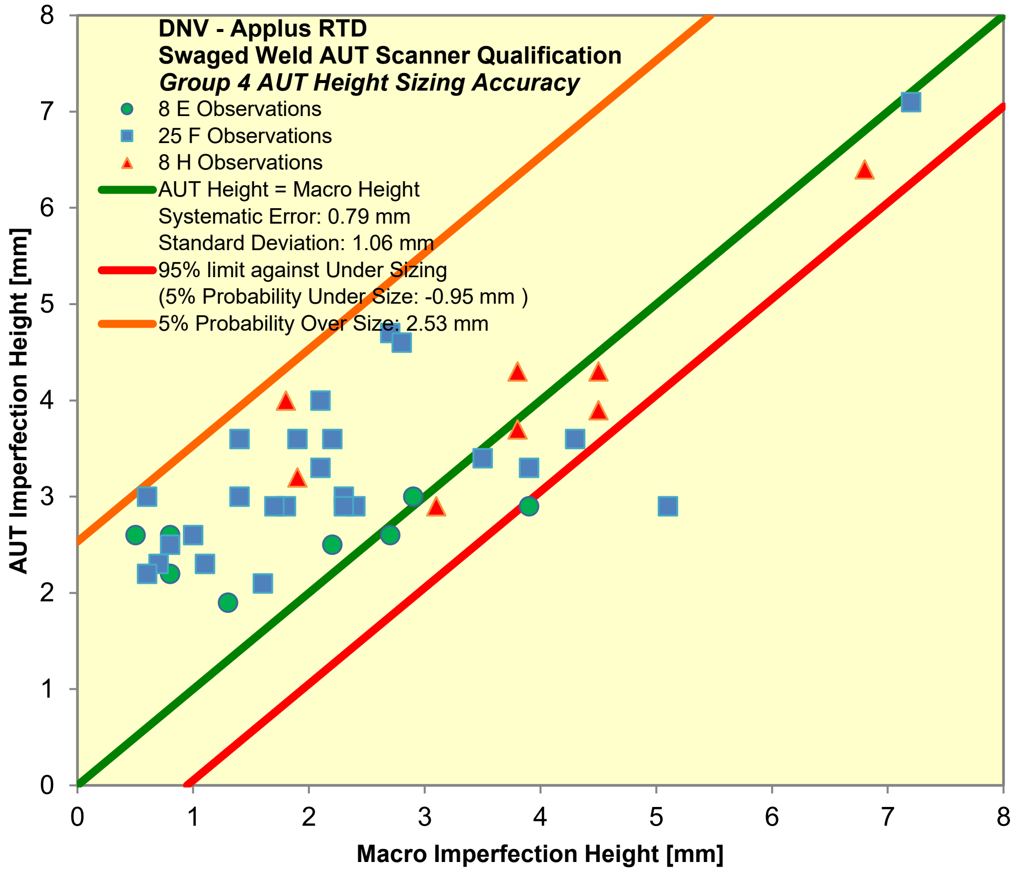

Figure 12: Horizontal width sizing accuracy plot of group 4 observations: E, F and H imperfections

6.4.6 Vertical Height Sizing Accuracy Group 5: F and H Imperfections

In total 17 imperfection observations have been included in the height sizing evaluation for this group, including 15 F-imperfections and 2 H-imperfections.

In general, height sizing in this group has been found to be less reliable than for the other groups. The main reason for this is assumed to be that the inspection set-up is not aimed at height sizing of these imperfections, as the primary detection by the PA3-probe offers solely width sizing capability. There are observed some considerable indications of F-imperfections with no height component detected, caused by height components in unfavourable positions and orientations. For H-imperfections, the height component is just occasionally detected and sized.

Height sizing of F imperfections close to the weld bevel face of the outer pipe is in addition possible by the PA1, PA2 and PA4 probes. When using this option, the -3 dB technique is used according to AUT procedure. The results presented here are used based on this information from these secondary detection probes.

The results from the sizing accuracy analysis are derived from the F and H imperfections where vertical height could be measured. A mean over sizing of 1.07 mm is found in this group as a unit, the standard deviation of the sizing inaccuracy is found at 0.80 mm. It has been estimated a less than 5% probability to under size group 1 imperfections more than -0.24 mm, as illustrated in Figure 13.

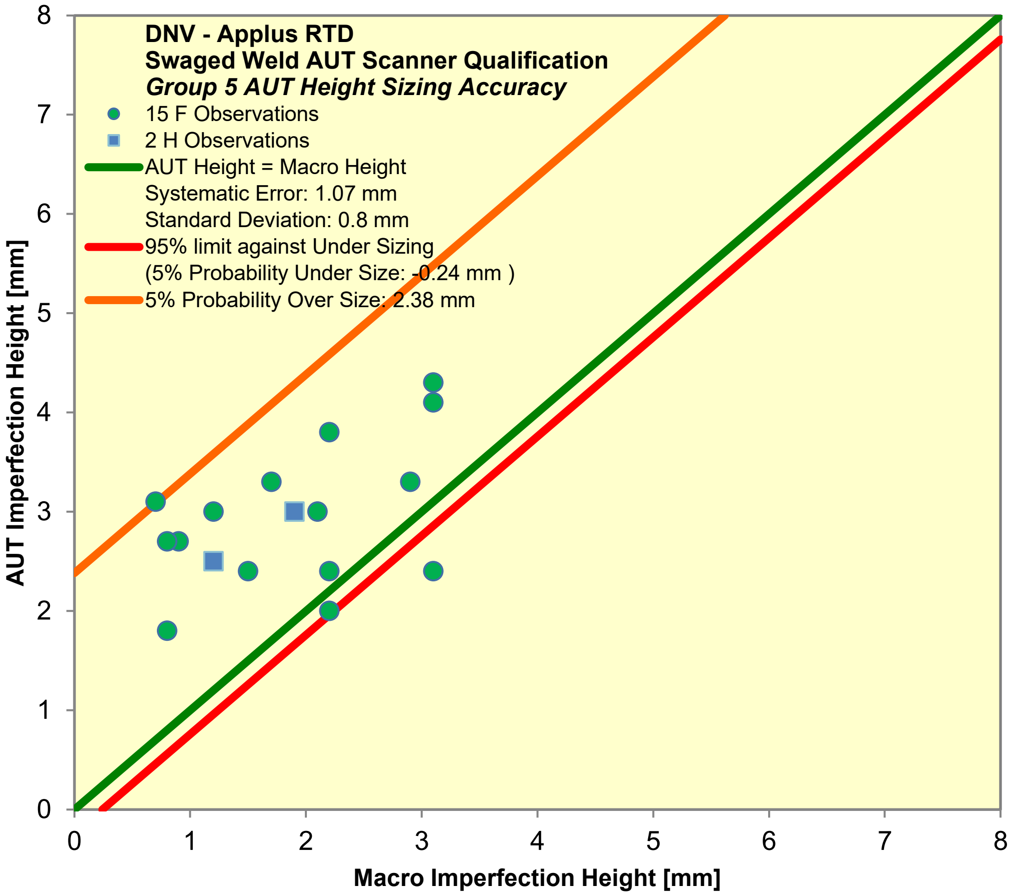

Figure 13: Vertical height sizing accuracy plot of group 5 observations: F and H imperfections

6.5 Length Sizing Accuracy

Length sizing accuracy has been evaluated, as the difference between AUT reported imperfection length and imperfection length confirmed by macro sectioning. In total 7 imperfections have been included in the analysis, these are 1 lack of root fusion (Ch), 2 lack of fusion (G and Bh), 1 vertical crack (Bv), 1 missed edge (D), 2 inter run lack of fusion (Cv and F) of lengths between 7 mm and 79 mm.

Length sizing by 20% FSH and 5% FSH amplitude thresholds and the -12 dB method for imperfection length were evaluated. The -12 dB method was found to be the more accurate. No under-sizing was observed when a 5% threshold was applied for imperfection length evaluation, however this was observed to be on the expense of huge over-sizing. The results using the -12 dB method are tabulated in Table 5 below. In general, imperfections are observed to be moderately over-sized in length.

Table 5: Length Sizing Accuracy Evaluation

Weld Number	AUT Indication	Type	Sizing Probe	Depth [mm]	Width [mm]	Height [mm]	Length AUT [mm]	Length Macro [mm]	Δ AUT-Macro [mm]
2	16	C	PA3	25.3	2.2	0	26	22	4
3	11	G	PA1	15	0	3.2	56	55	1
6	9	F0	PA3	37.8	4.3	0	78	79	-1
6	11	Bv	PA2	21	0	0.8	42	37	5
8	8	Bh	PA3	23.2	4.4	0	8	7	1
2B	M11	D	PA1	7	0	4.6	43	41	2
2B	M40	Cv	PA1	17.5	0	3.2	20	16	4

Further evaluation of length sizing accuracy has been performed on calibration block reference reflectors. Details on the reference reflectors are given in paragraph 5.1, Table 3. Concerning the reference reflectors, fabrication of the calibration block required the weld to be cut in order to correctly position reference notches E, F, Bv and G, and side drilled hole E. Due to this, the calibration block contains a vertical surface at the one of the ends of these reflectors, which will influence the length estimate. The reflectors A and D are induced with no cutting of the weld.

For length sizing accuracy by the -12 dB method on the reference reflectors a mean under sizing of -1.6 mm was observed, with a standard deviation of 4.7 mm. This corresponds to a less than 5% of under sizing more than -12.5 mm. Some of this under sizing can be attributed to the surfaces inside the calibration block.

6.6 Probability of Detection (POD)

6.6.1 General

Probability of Detection has been evaluated for the same sample of imperfections as for the sizing accuracy evaluation in group 1 to 3. Concerning group 4 and 5, it is regarded as not adequate to perform POD analysis based on imperfection vertical height for these groups, as the AUT scanner is not set up for detection of imperfection height at the interior of the weld. This issue is also discussed in paragraphs 5.3 and 6.4.6. Group 4 and 5 have therefore been merged for the POD analysis. The main argument for doing this is that it has been observed that E, F and H imperfections are repeatedly detected by the primary PA3 probe, regardless of orientation and imperfection geometry. It is regarded as sufficient that the AUT system as a whole has demonstrated capability to detect the imperfection, rather than looking into detection by different probes of certain parts of a imperfection.

6.6.2 Probability of Detection Group 1: D, G and Cv Imperfections

Detection of vertical D, G and Cv imperfections has in general been observed to be good. In addition to the primary detection by the PA1 scan, secondary detection by the PE5 probe showed reliable detection of embedded G-imperfections. All G-imperfections detected by PA1 gave indication in the PE5 scan.

The POD analysis shows a minimum 90% POD at 95% confidence level for imperfections of 0.8 mm vertical height and above, as shown in Figure 14. For the direct POD fit for the data set used (i.e. at 50% confidence level), 90% POD is found for imperfections of 0.7 mm vertical height.

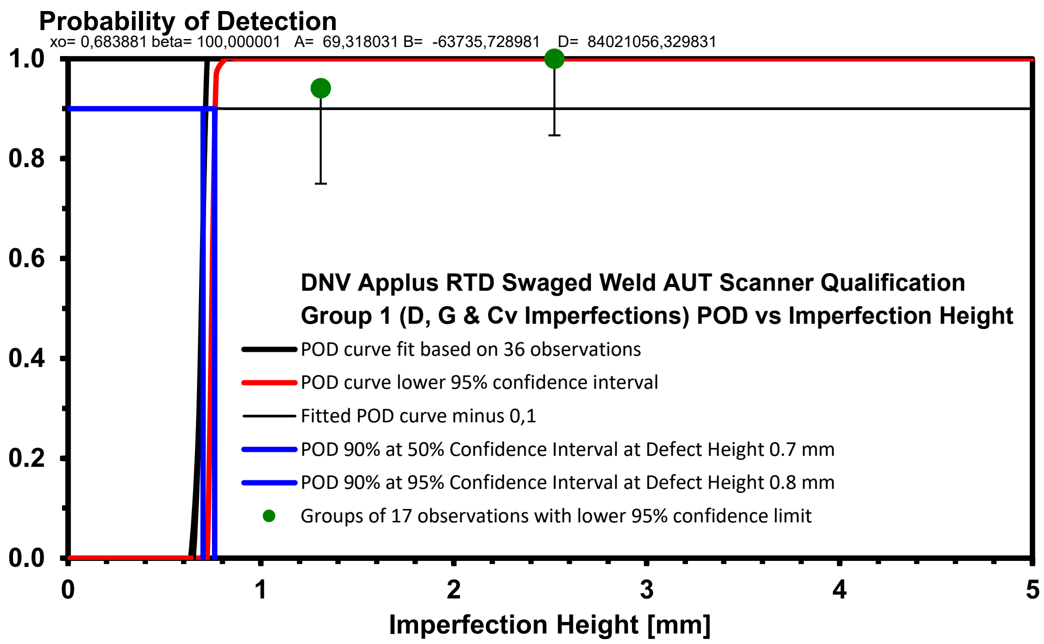

Figure 14: Estimated POD curve for Group 1 imperfections: D, G and Cv imperfections.

6.6.3 Probability of Detection Group 2: Bh and Ch Imperfections

Detection of horizontal Bh and Ch imperfections has in general been observed to be good. It was observed though, that when both Bh and Ch imperfections are at the same position and the Ch imperfection is the smaller, Bh, might mask the Ch imperfection.

The POD analysis shows a minimum 90% POD at 95% confidence level for imperfections of 1.0 mm vertical height and above, as shown in Figure 16. For the direct POD fit for the data set used (i.e. at 50% confidence level), 90% POD is found for imperfections of 1.0 mm vertical height.

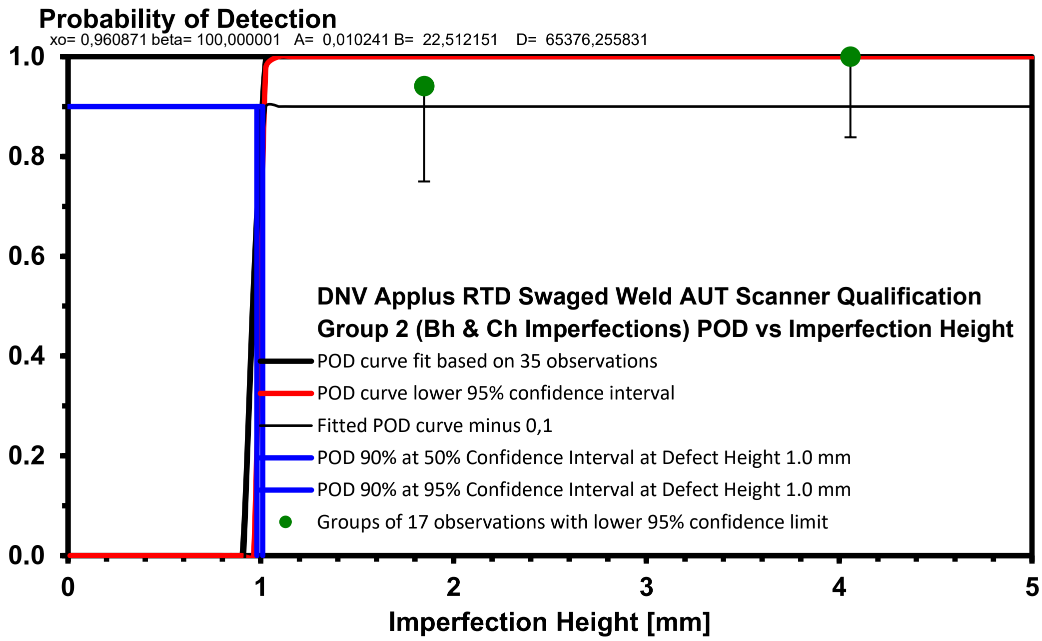

Figure 15: Estimated POD curve for Group 2 imperfections: Bh and Ch imperfections

6.6.4 Probability of Detection Group 3: Bv and A Imperfections

Detection of vertical Bv and A imperfections has been observed to be good. The use of both TOFD and sectorial PA scanning of the imperfection position is clearly an adequate approach to detect these imperfections. The majority of the induced imperfections used upon qualification were not fully vertical imperfections, but had usually a horizontal component as well.

The POD analysis shows a minimum 90% POD at 95% confidence level for imperfections of 0.9 mm vertical height and above, as shown in Figure 16. For the direct POD fit for the data set used (i.e. at 50% confidence level), 90% POD is found for imperfections of 0.8 mm vertical height.

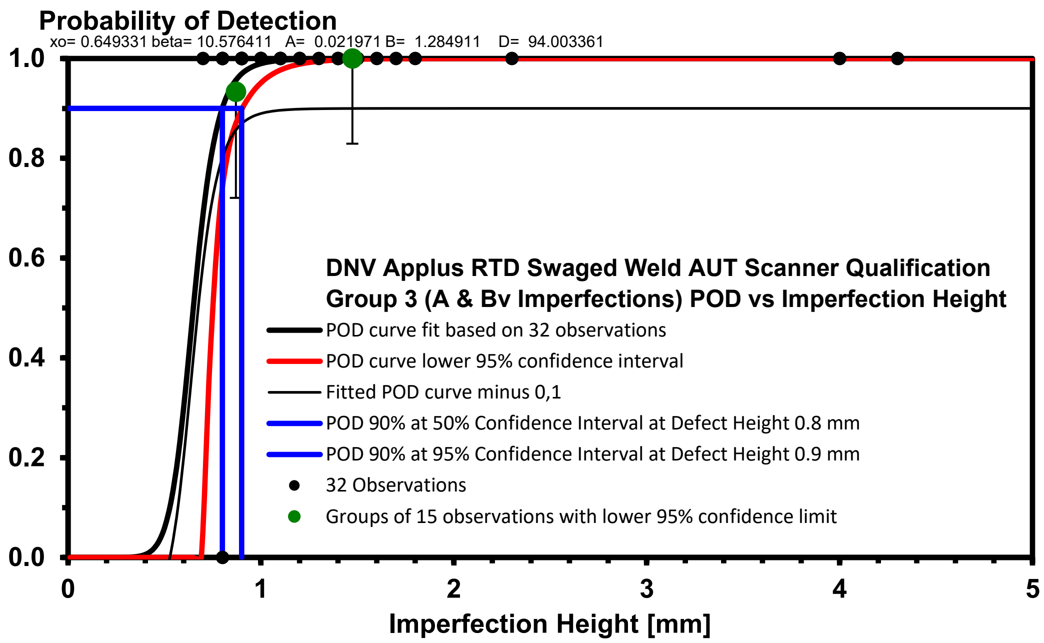

Figure 16: Estimated POD curve for Group 3 imperfections: Bv and A imperfections.

6.6.5 Probability of Detection Group 4 and 5: E, F and H Imperfections

Adequate detection is observed for group 4 and 5 imperfections. All imperfections are detected by the PA3 probe, therefore the imperfection width has been used as the imperfection dimension for the POD analysis. Further considerations are described in paragraph 6.6.1.

The POD analysis for group 4 & 5 imperfections shows a minimum 90% POD at 95% confidence level for imperfections of 0.8 mm horizontal width and above, as shown in Figure 17. For the direct POD fit for the data set used (i.e. at 50% confidence level), 90% POD is found for imperfections of 0.6 mm horizontal width.

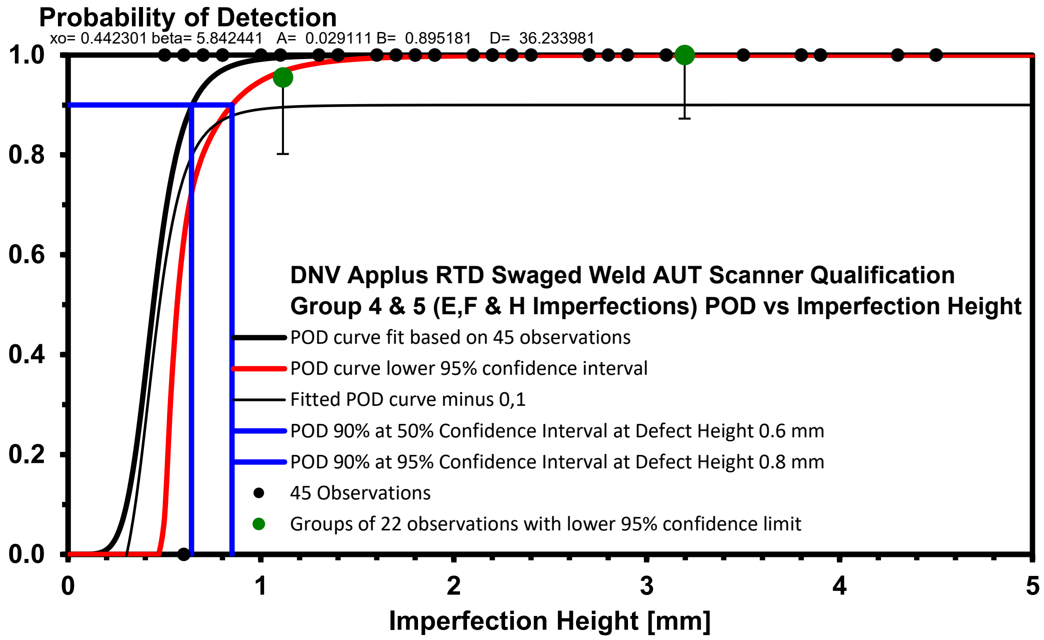

Figure 17: Estimated POD curve for group 4 & 5 imperfections: E, F and H imperfections.

6.7 Detection of Volumetric Imperfections

2 areas of cluster porosity were identified and macro sectioned. Porosity in the interior of the weld is mainly detected by the PA3 probe, and appears on the scan as a diffuse shading of low amplitude signal of parts of the volume. Macro sectioning confirmed porosity cluster at the identified locations.

Porosity was not induced to the trial welds by intention, as it was not a part of the original scope of work for the qualification. However, it was still demonstrated capability to detect this imperfection type through some naturally occurring porosity cluster imperfections in the welds. It should be mentioned that the signals from porosity were rather faint, as the qualified set-up is not focused on detection of this type of imperfections. Clusters were identified by scan evaluation at an increased gain of +12 dB. Due to their low ultrasonic response, they were not initially sized. This low ultrasonic response will require awareness from the AUT operator upon interpretation. Macro sectioning showed clear porosity clusters at the positions identified at the scans.

7 CONCLUSIONS

7.1 Introduction

The Applus RTD Swaged Weld AUT scanner system has been subject to qualification trials with respect to examination in general of carbon steel pipe swaged welds according to DNVGL-ST-F101, Appendix D and E. The qualification work has been done under agreement between Applus RTD and DNV GL AS, and follows the requirements for AUT qualification of DNVGL-RP-F118. The qualification trials have covered 8 swaged welds in a configuration with the inner pipe of 12” (323.8 mm) diameter and 20.6 mm nominal wall thickness, and the outer pipe of 16” (406.4 mm) diameter and 27.4 mm nominal wall thickness. The actual wall thickness for all of the trial welds were measured to be within the range of 17.9 mm to 22.7 mm for the inner pipe, and within 26.9 mm to 28.5 mm for the outer pipe. Macro sections of all of the trial welds showed a variation in the horizontal width of the weld between 33.6 mm and 42.4 mm. The root gap was found to vary between 1.7 mm and 5.6 mm. Swaging angle varied between 7.6º and 13.9º. The steel grade of the trial welds was X65. The defective welds and corresponding calibration blocks have been subjected to trials for reliability, repeatability and heat influence. In total 168 observations were included for further reliability analysis through macro sectioning. AUT inspection was performed according to procedure no. UT10280, Rev 6.0 [4]. Both scanning and macro sectioning were witnessed by DNV GL.

7.2 Performance data

Below are the results of the qualification, which is the documented performance of the Applus RTD Swaged Weld AUT scanner system with the set up and calibration for swaged weld inspection of the welds with configuration used for the trials. The results are valid for similar configurations, given that the prerequisites of paragraph 7.3 are fulfilled.

Relevant naturally occurring imperfection types have been identified and denoted with letters, as illustrated in Figure 18.

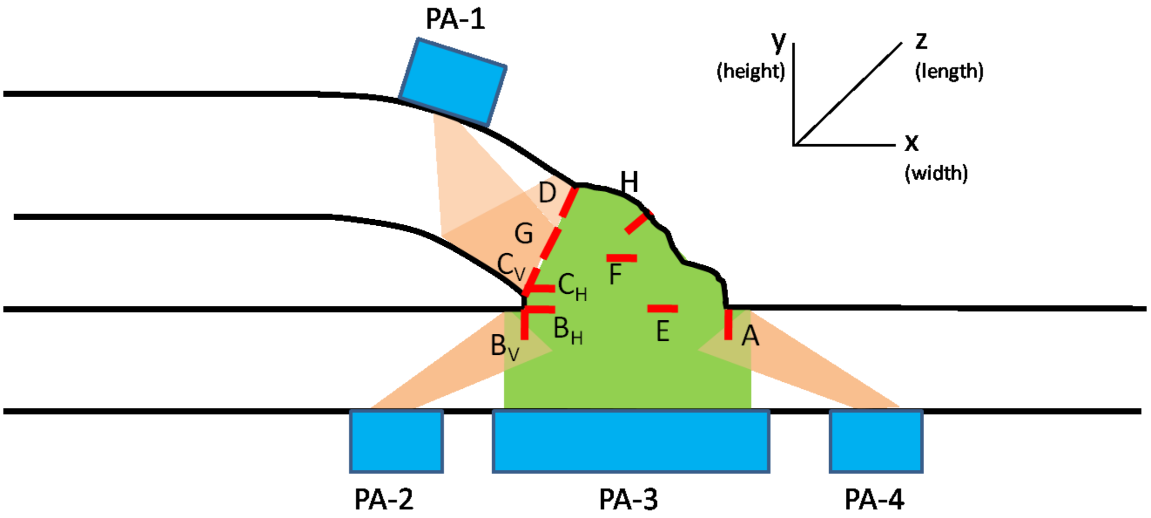

Figure 18: Relevant imperfection types to occur in swaged weld

The naturally occurring imperfection types have been grouped into 5 groups of imperfection types with similar detection characteristics. The groups used for further analysis are given in the Table 6 below.

Table 6: Imperfection Groups for Analysis					
	Group 1	Group 2	Group 3	Group 4	Group 5*
Imperfection types	Cv, G, D	Ch, Bh	Bv, A	E,F,H	F,H
Main Detected Dimension	Height	Width	Height	Width	Height
Main Detecting Probe	PA1	PA3	TOFD1, TOFD2	PA3	PA2, PA4*
# Observations (used for height size analysis)	36 (35)	35 (34)	33 (31)	45 (41)	19 (17)

*Group 5 consists of imperfections with primary detection by PA3 probe, included in group 4 as well. Height evaluation has been performed by the secondary detection probes PA1, PA2 and PA4 as well.

7.2.1 Repeatability

Repeatability tests on calibration block shows no deviations more than ± 1 dB in amplitude response from relevant calibration reflectors on repeated scans compared to an initial scan. This is well within the requirement of ± 2 dB amplitude deviation for repeated scans.

Band offset trials for the probes PA2, PA3 and PA4 shows no significant impact on performance at a band offset of 2 mm, i.e. repeated scans shows amplitudes within ± 2 dB. For the probes PA1 and PE5, the ± 2 dB criteria is maintained at a band offset of 1 mm.

7.2.2 Temperature

The Applus RTD Swaged Weld AUT scanner system detection and sizing capabilities has been found to be acceptable, with deviations in sizing of imperfection indications in defective welds found to be within ± 1 mm. The trials were performed at an elevated pipe temperature of 70°C, with the calibration block is kept at ambient temperature.

7.2.3 Height Sizing Accuracy

The height sizing accuracy is evaluated for each group independently. The analysis results for the main detected and sized dimension (width or height) are given in the table below. Any general recommendation on sizing accuracy allowance are not provided due to the distinct differences in sizing methodology and imperfection types between the groups.

Table 7: Imperfection sizing accuracy result summary					
	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Main Dimension	Height	Width	Height	Width	Height
5% Probability Under Sizing	-0.6 mm	-1.5 mm	-0.8 mm	-1.0 mm	-0.2 mm
Mean	0.6 mm	-0.1 mm	0.1 mm	0.8 mm	1.1 mm
Standard Dev.	0.76 mm	0.85 mm	0.55 mm	1.06 mm	0.80 mm

7.2.4 Length Sizing Accuracy

In general, a tendency of over-sizing in length is consistently observed. All 7 imperfections were observed with no less than -1 mm under-sizing. Length sizing was performed with the -12 dB drop method, which was concluded to be the most accurate method for length sizing.

7.2.5 Detectability

Reliable detection at 90% POD with 95% confidence is found within 0.8 mm and 1.0 mm imperfection height or width. Detection performance was evaluated from data of indications giving signals above noise level. The results for the different groups are given in the table below.

Table 8: Vertical Imperfection Heights of 90% POD at 95% confidence result summary				
	Group 1	**Group 2**	**Group 3**	**Group 4 & 5**
90%|95% POD Imperfection Height	0.8 mm	1.0 mm	0.9 mm	0.8 mm

7.3 Prerequisites

The performance documented in this report for the Applus RTD Swaged Weld AUT scanner system set up is regarded relevant for general use on carbon steel swaged welds with corresponding calibration and weld bevels, according to DNVGL-ST-F101 appendix D and E. In general, the requirements to the weld inspection are given in the Appendix D, which does not fully cover cases where ECA derived absolute acceptance criteria are applied. Requirements for AUT qualification given in DNVGL-ST-F101 appendix E are mainly dealing with pipeline girth weld inspection, however the methodology and criteria have been found relevant for this Swaged Weld application. These results can be used as a basis for project specific validation trials, and hereby limit the required scope of validation work. This is valid provided the prerequisites below are met.

No changes shall be made to the system including hardware, software and operating manuals and procedure that will influence the performance of the system with respect to 100% inspection coverage, imperfection detection and sizing (length, width and height), compared to what was achieved during the qualification. The cut-back on outer and inner pipe shall be sufficient for unhindered operation of the scanner. Swaged welds shall be made in carbon steel pipe material, with arc welding without backing rings, without major changes in the AUT system set-up. Variations in swaging and bevel angles, wall thickness, inner and outer pipe diameter, changes in bevel preparation or root gap are not considered major, as long as 100% weld coverage is maintained and the reference reflectors on calibration of the AUT remains as qualified. The width of the weld should not exceed the active aperture of the PA3 probe.

Detailed inspection technique documents, similar to the ones used during the qualification, shall be used for relevant welds in question taking material thickness and variations, bevel preparation details and other items relevant for inspection coverage into consideration.

The validity of the results shown in this report is mainly dependent on AUT scanner set-up for the different probes and on calibration. Modifications of the qualified AUT scanner set-up shall not cause reduced inspection performance. Phased array probe pitch is regarded as a significant parameter for sectorial scan set-ups only. It is then acceptable to increase the pitch of the PA3 probe without further validation. The same type of reference reflectors as during the qualification trials shall be used. Reflector sizes may be reduced (but not increased), provided that necessary area focus and resolution is maintained.

Qualified personnel as according to DNVGL-ST-F101 requirements shall be used.

7.4 Validity

The qualification has unlimited validation, given the prerequisites in section 7.3 are met. Compliance according to DNVGL-ST-F101 ensures compliance with all previous revisions of DNV-OS-F101 which includes requirements to AUT, i.e. the 2000, 2007, 2010, 2012 and 2013 editions.

8 REFERENCE DOCUMENTATION

[1] DNVGL Standard DNVGL-ST-F101: Submarine Pipeline Systems, edition October 2017

[2] DNVGL Recommended Practice DNVGL-RP-F118: Pipe girth weld automated ultrasonic testing system qualification and project specific procedure validation, May 2017

[3] Guidelines for NDE Reliability Determination and Description, Nordtest TechReport 394, Nordtest, Espoo, Finland, Approved 1998-04

[4] Procedure for Automated Ultrasonic Testing of Swaged Welds (Pipe-In-Pipe Welds), Doc. Ref. UT10280, Rev 6.0

[5] DNV-Applus RTD Swaged Weld Inspection Procedure Qualification, Ref. No. 1140-GL-10003-PIP, Draft 2, 13/05/2010.

[6] Interpretation Guideline for Swaged Weld, Ref. No. GL11006

[7] AUT Qualification Swaged Weld (S01), Exova ref. No S100505, rev 3, 07/08/2015

[8] AUT Qualification Swaged Weld (S02), Exova ref. No S100506, rev 2, 02/08/2011

[9] AUT Qualification Swaged Weld (S03), Exova ref. No S100507, rev 2, 03/08/2011

[10] AUT Qualification Swaged Weld (S04), Exova ref. No S100508, rev 2, 04/08/2011

[11] AUT Qualification Swaged Weld (S05), Exova ref. No S100509, rev 2, 04/08/2011

[12] AUT Qualification Swaged Weld (S06), Exova ref. No S100510, rev 3, 02/08/2011

[13] AUT Qualification Swaged Weld (S07), Exova ref. No S100511, rev 1, 30/06/2011

[14] AUT Qualification Swaged Weld (S08), Exova ref. No S100512, rev 3, 04/08/2011

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