METHOD AND DEVICE FOR ULTRASONIC INSPECTION

A method for ultrasonic inspection of a fillet weld. The method comprises ultrasonic inspection with the aid of a first ultrasonic phased array probe. The fillet weld forms a connection between a first pipe element and a second pipe element. The method comprises carrying out a first pulse-echo sector scan along a first part of a cross section of the fillet weld.
Title: Method and device for ultrasonic inspection

The invention relates to a method for ultrasonic inspection of a fillet weld. The invention further relates to a device for ultrasonic inspection of a fillet weld. The invention further relates to an inspection result.

Of fillet welds such as the circular welds of split T's and repair shells of gas lines, good ultrasonic manual inspection is hardly possible. It has been shown that only a part of the weld is inspectable, and that defects with a relevant size can hardly if at all be distinguished from small flaws acceptable per se.

It is an object of the invention to obviate at least one of these problems.

To this end, the invention provides a method for ultrasonic inspection of a fillet weld, the method comprising ultrasonic inspection with the aid of a first ultrasonic phased array probe.

The invention further provides a device for ultrasonic inspection of a fillet weld, wherein the device is provided with a first ultrasonic phased array probe. The invention further provides a first inspection result, such as a report, obtainable by means of a method according to the invention.

The invention will be illustrated with reference to the appended, non-limiting drawing, in which:

Fig. 1 shows dimension V of a reduced portion of the shell;
Fig. 2 shows a basic sketch of a reference block;
Fig. 3 shows an estimation of the orientation of a 6 mm-high fusion defect;
Fig. 4 shows the presence of a diffraction signal;
Fig. 5 shows a diffraction signal over skip;
Fig. 6 shows acceptance criteria;
Fig. 7 shows a photograph of a pipe (left/bottom), which may be part of a pipeline, and a split T (right/top), connected with a fillet weld extending in a circumferential direction of the pipe;

Fig. 8 shows an example of a phased array presentation;

Fig. 9 shows an example of a manufacturing drawing for a reference block (20/22 mm);

Fig. 10 shows a position determination of an indication;

Fig. 11 shows an overview photograph of a 36" split T at an inspection location;

Fig. 12 shows a scanning arrangement for phased array at an inspection location;

Fig. 13 shows inspection results RN 1 shell side;

Fig. 14 shows inspection results RN 1 pipe side;

Fig. 15 shows inspection results RN 1 indication 1;

Fig. 16 shows inspection results RN 1 indication 2;

Fig. 17 shows inspection results RN 2 shell side;

Fig. 18 shows inspection results RN 2 pipe side;

Fig. 19 shows inspection results RN 2 indication 1 (geometric indication);

Fig. 20 shows inspection results RN 2 indication 2;

Fig. 21 shows a position determination of an indication;

Fig. 22 shows an overview photograph of a 36" split T at an inspection location;

Fig. 23 shows a scanning arrangement for phased array at an inspection location;

Fig. 24 shows a problem with a welding mask at an inspection location;

Fig. 25 shows inspection results RN 1 shell side;

Fig. 26 shows inspection results RN 1 pipe side;

Fig. 27 shows inspection results RN 2 shell side; and

Fig. 28 shows inspection results RN 2 pipe side.
Paragraphs 1-13 contain *inter alia* a description of mechanized ultrasonic inspection of circular welds of split Ts and repair shells (carbon steel lines) by means of phased arrays, in exemplary embodiments according to the invention.

This procedure holds for ultrasonic inspection of circular welds of split Ts and repair shells, for pipe diameters ≥ 18", pipe wall thicknesses between 8 and 22 mm and shell thicknesses (if applicable the thickness of the reduced part) between 10 and 25 mm. However, a similar procedure may also be used for pipe diameters < 18", pipe wall thicknesses ≤ 8 mm or ≥ 22 mm, and/or shell thicknesses ≤ 10 mm or ≥ 25 mm. So, it will be clear that the procedure, as well as the similar procedures, is an example of a method for ultrasonic inspection of a fillet weld, wherein the method comprises ultrasonic inspection with the aid of a first ultrasonic phased array probe.

1. **General introduction**

Of the ultrasonic inspection with the aid of phased arrays, as described in this procedure, it has been determined that volumetric inspection is indeed possible. In addition, height determination of detected flaws is possible (to a limited extent) with this technique. It will be clear that such possibilities are not easy to recognize. Here, the fact comes in that it is generally known that a fillet weld has a location with respect to the pipe, and has a geometry, which differs much from a weld connecting two pipe parts which have a similar shape (i.e. with substantially the same diameter and wall thickness) in line with each other. The fillet weld will, for instance, be found as a connection between two pipe elements with mutually different diameters, such as for instance a repair shell with an inner diameter placed around the outer diameter of a pipe element, or a split T with an inner diameter placed around the outer diameter of a pipe element.

In the field of ultrasonic inspection, it has been known for a long time that
fillet welds, such as corner welds, are very difficult to inspect. The inspection preferably uses sector scans (pulse-echo technique).

An object of the inspection described in this procedure is detecting and locating weld flaws as well as determining the size (height) thereof. Detected indications are preferably judged as being relevant or not relevant. Relevant indications are preferably shown with both the length and the height of the indication. These relevant indications are judged as being acceptable or not acceptable with the aid of the applicable acceptance criteria.

The inspection is preferably carried out with two identical linear phased array probes, which are placed opposite each other on both sides of the weld (one on the pipe surface and one on the surface of the shell). So, it will be clear that, in this example, the weld (i.e. de fillet weld) forms a connection between the pipe and the shell. It will be clear that, here, the pipe has a different outer dimension than the shell. A first pulse-echo sector scan can be carried out along a first part of a cross section of the fillet weld with the aid of a first of the two ultrasonic phased array probes, which are, in this example, positioned on the surface of the pipe. (It will be clear that the pipe is an example of a first pipe element). This can lead to a first scan result. In addition, a second pulse-echo sector scan can be carried out along a second part of the cross section of the fillet weld with the aid of a second of the two ultrasonic phased array probes, which is, in this example, positioned on the surface of the shell. (It will be clear that the shell is an example of a second pipe element). This can lead to a second scan result. The first and the second scan result can be analyzed for determining the presence or absence of a defect in the first and/or second part of the cross section.

The weld is inspected with the aid of a mechanical scanner, guided by means of a guide band to thus move the probes along the weld in one movement.

A corner weld may be an example of a fillet weld.
2. **NDO staff**

2.1 *The group leader, who carries out the inspection, may:*
  - have level 2-UT or an equivalent level, according to EN 473.
  - be additionally trained in the use and interpretation of the phased array system.

2.2 *The assistant, who assists in the inspection, may:*
  - have SKO level 1-UT or an equivalent level, according to EN 473.
  - be trained in operating manipulators.

3. **Equipment**

3.1 **Scanner**

For the inspection, for instance, the RTD band scan is used. The scanner meets, for instance, the following requirements:

- Guidance by means of a steel guide band provided on the pipe side next to the weld;
- Is capable of guiding at least 2 cardan-suspended phased array probes; distance to the weld individually adjustable;
- The scanner can bridge a height difference between the probes up to about 25 mm (this corresponds to the maximum (optionally reduced) shell thickness);
- Couplant supply per probe;
- Cable length between scanner and vehicle about 10 meters;
- The scanner is equipped with a position indicator, which measures the distance on the surface of the pipe;
- Maximum scanning speed 40 mm/sec.

3.2 **Phased array probes**

Two identical phased array probes with wedges can be used, with, for instance, the following properties:
Type of array : Linear
Ultrasonic frequency : 10 MHz
Number of elements : 32
Element width : 7 mm
Pitch : 0.31 mm

The probe can be mounted on wedges with the following properties:

- Wedge material : Rexolite (CL = 2345 m/s)
- Primary wedge angle : 35°
- Probe building number : 07-1576 / 1577 or equivalent

3.3 Electronics

A phased array system with the following properties can be used:

- Number of channels : Minimally 64 (suitable for connecting 2 probes with 32 elements each)
- Number of simultaneously active channels : Minimally 32
- Visualization by means of : Sector scan, from both sides

The equipment can support the simultaneous carrying out of sector scans from two sides. In addition, pitch-catch mode can be supported (coupling check per probe, with a 0° angle).

In Fig. 8, an example of a sector scan recording is shown.

3.4 Check of equipment

The equipment preferably complies with RTD check procedure CP-31111 "Calibration check procedure for ultrasonic phased array equipment", latest revision.
3.5. **Calibration check of the encoder**

A test scan can be carried out over a known length. The displacement shown on the display corresponds to the path travelled on the pipe surface, with a tolerance of approx. 2.5%.

It will be clear that, herewith, an example of a device for ultrasonic inspection of a fillet weld is described, wherein the device is provided with a first ultrasonic phased array probe.

4. **Possible requirements to be imposed on the object to be inspected**

4.1. **Geometry / accessibility of the weld**

The section of the end of the shell is shown in Fig. 1 for the case where a reduction is applied to the shell. In order to accommodate the probe, the length of the reduced part (dimension V in the Figure) is preferably at least 30 mm.

4.2. **Couplant and surface condition**

Water or antifreeze can be used to acoustically couple the probes with the shell and pipe surface, respectively, in an ambient / surface temperature of -15 to +40 °C. In winter time, with use of antifreeze, preferably, a receiving bin is used.

The couplant is fed via the probes, between the probes and the pipe surface.

In order to guarantee a good acoustic contact between the probes and the pipe material, the probing surface is, preferably, on both sides of the weld over a width of at least 75 mm, free from welding spatters, coating and/or other flaws which can disturb the coupling. Also, preferably, the longitudinal welds of both the pipe and the shell are ground smooth over a distance of at least 75 mm for the benefit of an undisturbed probe run. The
sealing layer of the circular weld projecting above the split T is preferably also ground smooth for the benefit of an undisturbed probe run.

In case of a reduction, this distance is the length of the reduction and the adjoining radius.

5. **Weld identification and coordinate** system

The welds to be inspected may be provided with an unambiguous identification, which can be entered into the phased array system, so that it can be shown together with the measuring results.

The X coordinate used by the system is the weld length from the zero point on top of the pipe or a reference point to be defined in more detail with vertical pipe connections. The direction of rotation (= positive X direction) is viewed clockwise in the flow direction of the gas.

Exceptions can be recorded in the phased array system under "comments" and in the report.

6. **Possible setting of the equipment**

6.1. **Basic settings**

The equipment can be set as follows:

Number of simultaneously active elements: 32 for both probes

Sweeping range: 40 to 70° in steel for both probes

Angle increments: 2°

Averaging: 1x

Sampling frequency: 50 MHz

Frequency filters: Switched off

Gate start of probe on shell side: 10 mm from the point of entrance

Gate length of probe on shell side: 90 mm

Gate start of probe on pipe side: 10 mm from the point of entrance
Gate length of probe on pipe side : 110 mm
Measuring point density : 2 mm on the circumference of the pipe
Scan length : Circumference of pipe plus an overlap of 100 mm

6.1. Tools for sensitivity setting

The sensitivity setting can take place by means of a reference block according to Fig. 2. The working drawings for such reference blocks can be generated by an automatic module in Solid Edge, on the basis of given pipe and shell thicknesses.

Fig. 2 shows how the dimensions are chosen by the Solid Edge model on the basis of these data.

The "pipe thickness" and the "shell thickness" of the reference block to be used are preferably as close as possible to the pipe thickness and shell thickness of the component to be inspected. Deviations of at most plus or minus 5 mm are allowed.

For different thicknesses of pipe wall and shell, different reference blocks are available. If no reference block is available of which both the pipe thickness and the shell thickness are within the given tolerance, two blocks may be used (separately for setting of the probe on the shell and on the pipe side).

For all reference blocks, preferably the following agreements hold:

• A and E have a fixed value of 150 mm
• The total height H is equal to P+S+2 mm, wherein S is the shell thickness (S does not occur in the above drawing)
• Bored holes are cylinder holes, diameter 2 mm, 120° apex angle, depth 25 mm
• Notches are made by means of spark erosion, width 1 mm, length 20 mm
Notch depth is 2 mm for pipe wall thicknesses $\leq$ 15 mm, 2.5 mm for pipe wall thicknesses $>$15 mm, in accordance with the applicable acceptance criteria (see chapter 8).

Notches are spaced over the width such that all interspaces are equal.

- $B + C + D = 2S$
- $B = 0.7 \times S$
- $D = 0.4 \times S$
- $C = \text{approx. } 1.0 \times S$ (this is the balancing item and may deviate slightly)

Fig. 9 shows an example of a manufacturing drawing, as it is generated in this manner for a pipe thickness of 20 mm and a shell thickness of 22 mm.

6.2. Example of sensitivity setting and probe placement

The sensitivity setting is derived from CSW-05-E "DGS method", provided that not a 2-mm flat bottom bore, but a 2-mm high notch is used as a reference reflector.

Probe setting on shell side:

- Determine the point of entrance of the probe at an angle of entrance of 50°.
- Determine the optimal position of the probe on the reference block (shell side). This position corresponds to the optimal irradiation of reflector X (Fig. 2) with the 50° beam over half skip.
- With a shell thickness of 16 mm, the front of the probe will then be at the location of the transition between shell and welding material.
• With thicker shells, the probe is placed further back to achieve optimal reflection at 50°; in case of limited space (when a reduction is present), this may not be feasible, but the probe is preferably placed as far back as is possible (therefore the probe is provided with an oblique side at the back).

• With thinner shells, the probe is placed further forwards. The allowable maximum distance over which the probe can be placed forwards ("overhang") is 7 mm. This is to ensure that the complete beam enters the material.

• From the optimal position, the maximum reflection of notch X is set at 80% BSH + 6 dB. This value is referred to as $H_r$ (reference amplitude).

• It is ensured that the bores are visible with this sensitivity. The amplitude is purely indicative.

• After the calibration, the set sensitivity is documented by means of a calibration scan of the reference block with the respective probe.

• When the probe is built in in the scanner, the position of the probe is corrected for the difference in wall thickness between the reference block and the shell (the reduced thickness applies: forwards with a thinner shell, backwards with a thicker shell). This is to ensure that defects of the type X are still optimally irradiated with the 50° beam. The correction $c$ in mm is $\Delta d \times \tan 50°$, i.e. $1.2 \times \Delta d$, $\Delta d$ being the difference in wall thickness in mm.

• Sensitivity correction is described later (transfer measurement).

• Correction for the differences in path of sound in the wedge for the different angles ("apodization") is not applied.
Probe setting on pipe side:

- Determine the point of entrance of the probe at an angle of entrance of 50°.

- Determine the optimal position of the probe on the reference block (pipe side). This position corresponds to the optimal irradiation of reflector Z (Fig. 2) with the 50° beam over full skip.

- With the thinnest pipe (8 mm), the probe will then abut the weld (if not, put it backwards as far as necessary), with larger thicknesses, it will be further backwards.

- From the final position, the maximum reflection of notch Z is set at 80% BSH + 12 dB. This value is referred to as \( H_r \) (reference amplitude).

- It is ensured that the reflections of the bores are visible with this sensitivity. The amplitude is purely indicative.

- After the calibration, the set sensitivity is documented by means of a calibration scan of the reference block with the respective probe.

- When the probe is built in in the scanner, the position of the probe is corrected for the difference in wall thickness between the reference block and the pipe: forwards with a thinner pipe (if possible), backwards with a thicker pipe. This is to ensure that defects of the type Z are still optimally irradiated with the 50° beam over skip. The correction in mm is \( 2 \times \Delta d * \tan(50°) \), i.e. \( 2.4 \times \Delta d \), \( \Delta d \) being the difference in pipe in mm.

- Sensitivity correction is described later (transfer measurement).
• Correction for the differences in path of sound in the wedge for the different angles ("apodization") is not applied.

**Sensitivity correction by means of transfer measurement:**

5 • Prior to building in the probes, a transfer measurement is carried out.

• Place the two probes opposite each other in their optimal position for the reference block.

• If for the sensitivity setting two different blocks are used, then choose for the transfer measurement the block of which the sum of the pipe thickness and shell thickness comes closest to the sum of the pipe thickness and shell thickness of the component to be inspected.

• Of both probes, the angle is varied to optimize the transfer signal (both angles do remain the same).

• Record the amplitude of the transfer signal (A).

• After building in the probe, the angle of both probes is again varied to optimize the transfer signal (both angles the same). Let the scanner run over a distance of e.g. 100 mm and record the average echo height (B).

• The difference between A and B is the transfer correction. This is applied to both probes.

**Coupling check:**

On both probes, a perpendicular beam (0°) is set as a coupling check. Alternatively, the irradiation (transfer) echo may be used.

### 7. Possible manner of carrying out the inspection

After the phased array system has been set and the probes have been built in, one may proceed as follows:
• Provide the guide band, position the scanner on the pipe, where the zero point is, and check the probe distance and whether the probes abut well.

• Switch on the supply of the couplant.

• Now switch on the system and have the weld scanned, at a speed of maximally 40 mm/sec, yet in any case not so fast that any data are missed.

• Scan the weld completely, with an overlap of 100 mm.

• If necessary, the scans may be made with both probes separately.

• If the scan contains an indication with amplitude > 100% BSH, the scan is preferably scanned again with a lower sensitivity in order to be able to determine the height of the amplitude.

It will be clear that the scanning of the weld referred to in this example comprises moving the first phased array probe along the pipe surface and moving the second phased array probe along the shell surface, in a circumferential direction of the pipe, for scanning along a plurality of cross sections of the weld (i.e. the fillet weld). It will be clear that, in this example, the fillet weld forms a connection between the pipe and the shell.

8. Example of interpretation of the result

8.1. Purpose of the interpretation

The purpose of the interpretation is preferably twofold:

• determining the presence of relevant indications.

• characterizing and determining the height of found defects.

Here, the measured height of any defect in millimeters is compared with that of the reference reflector (2 mm-high notch).
Determining indications and height determination particularly take place at the following locations:

<table>
<thead>
<tr>
<th>Defect location</th>
<th>To be determined with which probe</th>
<th>Reference reflector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell – weld fusion line (below)</td>
<td>Probe on shell side</td>
<td>Notch X</td>
</tr>
<tr>
<td>Shell – weld fusion line (above)</td>
<td>Probe on shell side</td>
<td>Notch Y</td>
</tr>
<tr>
<td>Large fusion defect</td>
<td>Probe on shell side</td>
<td>Screening of geometry signal</td>
</tr>
<tr>
<td>Underbead crack</td>
<td>Probe on pipe side</td>
<td>Notch Z</td>
</tr>
<tr>
<td>Defects in the weld volume</td>
<td>Both probes</td>
<td>Bore in the weld center</td>
</tr>
</tbody>
</table>

- Determine whether indications come or do not come from geometry.
- Non-geometric indications are relevant indications: they are preferably evaluated from an echo height of 20% BSH (after deduction of the scan sensitivity).

8.2. Possible characterization and sizing of indications on the fusion line between shell and weld

It is determined:

- whether or not a diffraction signal from the flaw tip is obtained;
- what is approximately the orientation of the defect;
- whether a small or large defect is involved.

The orientation is determined by ascertaining in what angle range the largest reflection takes place (defects of the sheD - weld fusion line). See Fig. 3 (in which a 6 mm-high defect is used as an example). With a flaw
orientation at 0° (perpendicular to the surface), particularly the angle effect will prevail, received with angles around 45°. With a flaw orientation of about 45°, particularly the plane of the flaw will prevail; also received with angles of around 45°, but over a smaller angle range (as a result of the directive efficiency of the mirroring flaw). A flaw oriented according to an angle halfway between 0 and 45° is particularly detected with angles in the higher range.

For a fusion defect between shell and weld, it holds that a small defect is present if it is concluded that it is oriented vertically, no diffraction signal is present and the geometry signal is not interrupted.

In such cases, for an approximation of the flaw height, the amplitude is used. An amplitude equal to the corresponding notch (X or Z) means a height of 2 mm. A smaller signal means a height of < 2 mm.

If a diffraction signal is obtained, it is preferably used to determine the height.

Fig. 4 gives an example of an angle effect signal (the second signal on the A image) combined with a diffraction signal (the first signal).

Preferably, it is attempted to measure the distance in time delay between the angle signal and the diffraction signal in the A image of one single angle. This increases the accuracy (different angles have different time delays in the wedge, which makes a combination of signals from different beams inaccurate). The flaw height is calculated from this time delay difference, divided by the cosine of the respective angle.

If a defect at the location of notch X is so large that its diffraction signal cannot be seen anymore, even not with the most level angle (70°), use can be made of a diffraction signal found over skip (the second signal in Fig. 5).
8.3. Characterization and sizing of indications on the pipe side (underbead crack)

Preferably it is determined:

- whether or not a diffraction signal from the flaw tip is obtained;
- what is approximately the orientation of the defect;
- whether a small or large defect is involved.

For an underbead defect, it holds that a small defect is present if no diffraction signal is present and the defect is not found with the probe on the shell side (so on the other side).

In such cases, for an approximation of the flaw height, the amplitude is used. An amplitude equal to the corresponding notch (Z) means a height of 2 mm. A smaller signal means a height of < 2 mm.

If a diffraction signal is obtained, this is preferably used to determine the height.

8.4. Length determination of defects

Length determination of defects is preferably done according to the amplitude half-value method. The amplitude half-value method is known per se to a skilled person, so that a further explanation thereof is deemed unnecessary.

9. Acceptance criteria

Acceptance criteria are preferably based on the applicable standard for the acceptability of weld flaws.

Because the phased array inspection may have a flaw height as a result, and is, in this sense, similar to ToFD, the acceptance criteria are, for instance, identical to those for the ToFD inspection.
The acceptance criteria for weld flaws are, for instance (see Fig. 6):

<table>
<thead>
<tr>
<th>Nominal wall thickness $d_a$ (mm)</th>
<th>Maximum allowed length ($l_{\text{max}}$) and height $h$ of defects (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exiting defects</td>
</tr>
<tr>
<td>$8.0 &lt; d_a \leq 15.0$</td>
<td>$l_{\text{max}, h3}$ $h_3$</td>
</tr>
<tr>
<td>$15.0 &lt; d_a \leq 25.0$</td>
<td>$2 \cdot d_d$ $2.0$</td>
</tr>
<tr>
<td>0</td>
<td>$\frac{1}{2} \cdot D \leq 300$</td>
</tr>
<tr>
<td></td>
<td>$h_1$</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>

Defects of the type X, Y and Z are considered exiting.

It may further hold that:

A group of indications, of which the individual indications are acceptable, is only acceptable provided that all following conditions are met:

a) The distance between successive indications in longitudinal direction of the weld is larger than or equal to the average length of the indications.

b) The distance between two successive indications in the thickness direction of the weld is larger than or equal to the height of the highest indication plus 50%.

c) No two or more flaws situated above each other having a height of more than 1.5 mm each are present, irrespective of the position in width location of the weld.

d) The sum of the length of the individual indications is smaller than or equal to $7 \cdot c_k$ measured over any length from $\frac{1}{2} \cdot D$ to maximally 300 mm in longitudinal direction of the weld.

Indications that do not meet the above conditions ad a), ad b) and ad c) are preferably treated as one indication. The defect dimensions ("h"
and "l") can then be measured including the distance between the indications and the table can be used for the evaluation.

If flaw height determination with phased array is impossible, the following criteria can hold:

- Any reflection of more than 80% BSH is rejected at a length exceeding 10 mm, irrespective of location and position of the weld.
- If reflection values are between 40% and 80% BSH, the height of the indication is taken as being equal to \( h_z \) and the allowable length is equal to \( \max(h_3) \).
- If the reflection values are between 20% and 40% BSH, the indications are viewed as \( h_1 \) and the allowable length is equal to \( l_{\max} h_i \).
- For the length determination, the amplitude half-value method is used.

Indications in the volume of the weld are reported with an amplitude \( \geq 20\% \) BSH, when their length is \( \geq 10 \) mm.

10. **Report**

The results of the inspection can be reported in the format below.

Relevant indications in a scan can be reported with their circumferential position on the pipe surface and their position in depth direction.

<table>
<thead>
<tr>
<th>Weld identification number</th>
<th>( X_1 ) [mm]</th>
<th>( X_2 ) [mm]</th>
<th>( l ) [mm]</th>
<th>( Z_1 ) [mm]</th>
<th>probe angle [°]</th>
<th>( h ) [mm]</th>
<th>Amplitude [% BSH]</th>
<th>Position of indication</th>
<th>Acc./N.A.</th>
</tr>
</thead>
</table>

Ace. = acceptable; N.A. = non-acceptable; cbd = cannot be determined; geom. = geometric indication
Further, the report preferably comprises:

- inspection date
- names and qualifications of the inspectors
- equipment used
- weld number / zero point
- diameter
- wall thickness of pipe and shell

11. Example

Fig. 7 shows a photograph of a pipe (left/bottom), which may be part of a pipeline, and a split T (right/top), connected with a fillet weld extending in a circumferential direction of the pipe. It will hence be clear that the fillet weld forms a connection between a first pipe element (here: the pipe left/bottom) and a second pipe element (here: the split T right/top). Here, it can clearly be seen that the split T has a larger diameter than the pipeline, so that the weld connection forms the fillet weld, here a corner weld. In this example, a pipe part of the split T has a larger diameter near the fillet weld than a pipe part of the pipe near the fillet weld. The split T may, for instance, be considered a split T-section or a split sleeve, for instance for the purpose of a branch. It will be clear from Fig. 7 that, more generally, a dimension of the fillet weld, measured in a longitudinal direction of the first pipe element such as the pipe, decreases in a direction from an inside of the first pipe element towards, and perpendicular to, an outside of the first pipe element. So, parts of the fillet weld located further from the pipe extend less far along the pipe. In other words, the fillet weld becomes increasingly narrower in a direction from the inside of the pipe to the outside of the pipe.
12. **Practical example: inspection of the circular welds of the 36” split T for the benefit of valve 1.**

Summary of the results: During the phased array inspection of RN 1 and RN 2, one indication has been observed in RN 1 which leads to rejection of the weld; on the other hand, RN 2 is acceptable according to the procedure.

12.1 Reason

A pilot project has been started. The circular welds of the 36” split T are inspected with the aid of the phased array inspection.

The inspection is carried out with the ultrasonic phased array technique.

12.2 Inspection program

Inspection of the circular welds of the 36” split T for the benefit of valve 1 by means of phased array.

Deviation in research program: No

12.3 Mode of carrying out

12.3.1 Inspection procedure

Inspection procedure used: UT-07147, rev. 3 (draft)

Deviations from the procedure: None

12.3.2 Object data

Type of object: Split T

Object identification: Line for the benefit of valve 1

Material: C-steel
Shell wall thickness : 20 mm
Pipe wall thickness : 14 mm
Pipe diameter : 36"
Surface temperature : 15 °C.
Surface condition : Brushed
Coating : No

12.3.3 Equipment data and settings

Equipment used : TD Focus Scan
Registration : SN0069
Calibration expiry date : 
Software version : TD-scan 17.00
Manipulator type : Band scan
Registration : 001
Reference block : P20-S22
Registration : P20-S22
Shell sensitivity setting : 80% BSH + 6 dB on notch X with 50° beam
Pipe sensitivity setting : 80% BSH + 12 dB on notch Z with 50° beam
Couplant : Water
Probe distance shell side : 24 mm
Probe distance pipe side : 36 mm
Frequency and elements of shell : 10 MHz - 32
Registration : 07-1577
Frequency and elements of pipe : 10 MHz - 32
Registration : 07-1576
12.3.4 Inspection locations

Both circular welds of the 36" split T have been inspected by means of phased array inspection. The longitudinal weld on the bottom side of the split T has been used as a zero point. The direction of scanning and numbering of the welds are shown in Figs. 11-20.

The photographs are added in Figs. 11 and 12.

12.4 Results

During the phased array inspection of RN 1 and RN 2, one indication has been observed in RN 1 which leads to rejection of the weld; on the other hand, RN 2 is acceptable according to the procedure.

The results of the inspection are included in the table below:

<table>
<thead>
<tr>
<th>Weld identification number</th>
<th>X₁ [mm]</th>
<th>X₂ [mm]</th>
<th>L [mm]</th>
<th>Z₁ [mm]</th>
<th>probe angle [°]</th>
<th>h [mm]</th>
<th>Amplitude [% BSH]</th>
<th>Position of indication</th>
<th>Acc./N.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN 1</td>
<td>192</td>
<td>218</td>
<td>26</td>
<td>19.5</td>
<td>52</td>
<td>cbd</td>
<td>25</td>
<td>X</td>
<td>Acc.</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>1030</td>
<td>630</td>
<td>18.0</td>
<td>52</td>
<td>cbd</td>
<td>60</td>
<td>X</td>
<td>N.A.</td>
</tr>
<tr>
<td>RN 2</td>
<td>552</td>
<td>1066</td>
<td>514</td>
<td>20.0</td>
<td>40</td>
<td>cbd</td>
<td>48</td>
<td>X (geom.)</td>
<td>Acc.</td>
</tr>
<tr>
<td></td>
<td>610</td>
<td>630</td>
<td>20</td>
<td>18.0</td>
<td>54</td>
<td>cbd</td>
<td>24</td>
<td>X</td>
<td>Acc.</td>
</tr>
</tbody>
</table>

Acc. = acceptable; N.A. = non-acceptable; cbd = cannot be determined; geom. = geometric indication

The phased array scans have been printed and added in Figs. 13-20.

The shell on RN2 side is probably reduced on the inside. Therefore, this is judged as being a geometric indication.

12.5 Recommendation

None
13. **Practical Example: Inspection of the circular welds of the 30" split T for the benefit of valve 2.**

Summary of the results: During the phased array inspection of RN 1 and RN 2, no indications have been observed which lead to rejection of the welds. Accordingly, both welds are acceptable according to the procedure.

**13.1 Reason**
A Pilot project has been started. The circular welds of the 30" split T are inspected with the aid of the phased array inspection.

The inspection is carried out with the ultrasonic phased array technique.

**13.2 Inspection program**
Inspection of the circular welds of the 30" split T for the benefit of valve 2 by means of phased array.

**13.3 Mode of carrying out**

**13.3.1 Inspection procedure**

Inspection procedure used: UT-07147, rev. 3 (draft)

Deviations from the procedure: None

**13.3.2 Object data**

Type of object: Split T

Object identification: Pipe for the benefit of valve 2
### Equipment data and settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>C-steel</td>
</tr>
<tr>
<td>Shell wall thickness</td>
<td>15 mm</td>
</tr>
<tr>
<td>Pipe wall thickness</td>
<td>18 mm</td>
</tr>
<tr>
<td>Pipe diameter</td>
<td>30&quot;</td>
</tr>
<tr>
<td>Surface temperature</td>
<td>15 °C</td>
</tr>
<tr>
<td>Surface condition</td>
<td>Brushed</td>
</tr>
<tr>
<td>Coating</td>
<td>No</td>
</tr>
</tbody>
</table>

13.3.3 Equipment data and settings

- **Equipment used**: TD Focus Scan  
  Registration: SN0069

- **Calibration expiry date**:  
- **Software version**: TD-scan 17.00
- **Manipulator type**: Band scan  
  Registration: 001
- **Reference block**: P20-S22  
  Registration: P20-S22

- **Shell sensitivity setting**: 80% BSH + 6 dB on notch X with 50° beam
- **Pipe sensitivity setting**: 80% BSH + 12 dB on notch Z with 50° beam
- **Couplant**: Water
- **Probe distance shell side**: 24 mm
- **Probe distance pipe side**: 36 mm
- **Frequency and elements of shell elements no.**: 10 MHz - 32  
  Registration: 07-1577

.
13.3.4 Inspection locations
Both circular welds of the 30" split T have been inspected by means of phased array inspection. The longitudinal weld on the bottom side of the split T has been used as a zero point. The direction of scanning and numbering of the welds are shown in Figs. 22-28.

The photographs are added in Figs. 22-24

13.4 Results
During the phased array inspection of RN 1 and RN 2, no indications have been observed which lead to rejection of the welds. Accordingly, both welds are acceptable according to the procedure.

The results of the inspection are included in the table below:

<table>
<thead>
<tr>
<th>Weld identification number</th>
<th>X₁ [mm]</th>
<th>X₂ [mm]</th>
<th>l [mm]</th>
<th>Z₁ [mm]</th>
<th>probe angle [°]</th>
<th>h [mm]</th>
<th>Amplitude [% BSH]</th>
<th>Position of indication</th>
<th>Acc./N.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Acc.</td>
</tr>
<tr>
<td>RN 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Acc.</td>
</tr>
</tbody>
</table>

Ace. = acceptable; N.A. = non-acceptable; cbd = cannot be determined; geom. = geometric indication

The phased array scans have been printed and added in Figs. 25-28.

13.5 Recommendation
In order to be able to completely inspect the weld from the shell side, in the future, if this is possible, the projecting weld layer which projects above the reduction is preferably removed (see Figs. 22-24).
CLAIMS

1. A method for ultrasonic inspection of a fillet weld, wherein the method comprises ultrasonic inspection with the aid of a first ultrasonic phased array probe.

2. A method according to claim 1, wherein the fillet weld forms a connection between a first pipe element and a second pipe element, wherein the method comprises the following steps:
   a) carrying out a first pulse-echo sector scan along a first part of a cross section of the fillet weld with the aid of the first ultrasonic phased array probe, which is positioned near the surface of the first pipe element, leading to a first scan result;
   b) carrying out a second pulse-echo sector scan along a second part of the cross section of the fillet weld with the aid of a second ultrasonic phased array probe, which is positioned near the surface of the second pipe element, leading to a second scan result, wherein the second ultrasonic phased array probe is optionally formed by the first ultrasonic phased array probe, and wherein preferably the first and the second part of the cross section together comprise the whole cross section of the fillet weld; and
   c) analyzing the first and the second scan result for determining the presence or absence of a defect near the cross section.

3. A method according to claim 2, comprising repeatedly carrying out the steps a)-c), and further comprising the step of:
   d) moving the first phased array probe along the first surface and moving the second phased array probe along the second surface, in a circumferential direction of the first or second pipe element, for scanning along a plurality of cross sections of the fillet weld.
4. A method according to claim 2 or 3, comprising the step of:
   e) locating the defect in the fillet weld.

5. A method according to any one of claims 2-4, comprising the step of:
   f) determining a dimension of the defect in the fillet weld, preferably
   followed by comparing the dimension of the defect with predetermined
   acceptance criteria.

6. A method according to any one of claims 2-5, wherein the first pipe
   element is formed by a pipe, which is preferably part of a pipeline, and the
   second pipe element is formed by a split T or a repair shell for the pipe.

7. A device for ultrasonic inspection of a fillet weld, wherein the
   device is provided with a first ultrasonic phased array probe.

8. A device according to claim 7, wherein the fillet weld forms a
   connection between a first pipe element and a second pipe element, wherein
   the device comprises:
   a) the first ultrasonic phased array probe, arranged for carrying out a
      first pulse-echo sector scan along a first part of a cross section of the fillet
      weld, wherein the first ultrasonic phased array probe is operatively
      positioned near the surface of the first pipe element, leading to a first scan
      result;
   b) a second ultrasonic phased array probe, arranged for carrying out a
      second pulse-echo sector scan along a second part of the cross section of the
      fillet weld, wherein the second ultrasonic phased array probe is operatively
      positioned near the surface of the second pipe element, leading to a second
scan result, wherein preferably the first and the second part of the cross section together comprise the whole cross section of the fillet weld; and
c) a processing unit for analyzing the first and the second scan result for determining the presence or absence of a defect near the cross section.

9. An inspection result, such as a report, obtainable through a method according to any one of claims 1-6.

10. A method for ultrasonic inspection of a pipe segment with a stepped diameter, wherein the pipe segment comprises a first pipe part with a first diameter and a second pipe part with a larger, second diameter, wherein the method comprises the following steps:
a) positioning a first ultrasonic phased array probe on the first pipe part and carrying out a first pulse-echo sector scan along a first part of a cross section of the pipe segment, preferably in the direction of the second pipe part, leading to a first scan result;
b) positioning a second ultrasonic phased array probe on the second pipe part and carrying out a second pulse-echo sector scan along a second part of the cross section, preferably in the direction of the first pipe part, wherein the second part preferably at least partly overlaps with the first part, leading to a second scan result; and
c) analyzing the first and the second scan result for determining the presence or absence of a defect in the first and/or second part of the cross section.

11. A method according to claim 10, wherein the first ultrasonic phased array probe and/or the second ultrasonic phased array probe is moved in a circumferential direction of the pipe segment.
12. A method according to claim 11, wherein the first ultrasonic phased array probe and the second ultrasonic phased array probe are moved synchronously.

13. A method according to any one of claims 10-12, wherein the first pipe part is connected to the second pipe part via a fillet weld.

14. A method according to any one of claims 10-13, wherein the first pipe part is formed by a pipe and the second pipe part is formed by a split T or a repair shell for the pipe, or wherein the second pipe part is formed by a pipe and the first pipe part is formed by a split T or a repair shell for the pipe.

15. A method according to any one of claims 1-6 or 10-14, comprising setting a sensitivity of at least the first phased array probe, and preferably both the first and the second phased array probe, wherein the sensitivity setting takes place by means of a reference block, wherein dimensions of the reference block are chosen on the basis of a wall thickness of the first pipe element and a wall thickness of the second pipe element, or wherein dimensions of the reference block are chosen on the basis of a wall thickness of the first pipe part and a wall thickness of the second pipe part.

16. A method according to any one of claims 1-6 or 10-15, wherein a diffraction signal of a tip of the defect is used to determine a height of the defect.

17. A method according to any one of claims 1-6 or 10-16, wherein an orientation of the defect is determined by ascertaining in what angle range of the first and/or second phased array probe the largest reflection takes place.
18. A method according to any one of claims 1-6 or 10-17, comprising analyzing the first and the second scan result for determining the presence or absence of a defect on a fusion line between the fillet weld and the first pipe element or the first pipe part, and/or comprising analyzing the first and the second scan result for determining the presence or absence of a defect on a fusion line between the fillet weld and the second pipe element or the second pipe part.
Fig. 12
FIG. 28
28/28
**INTERNATIONAL SEARCH REPORT**

A. **CLASSIFICATION OF SUBJECT MATTER**

INV. G01N29/07 G01N29/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. **FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. **DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>X</td>
<td>WO 2005/045418 A (ROENTGEN TECH DIENST BV, [NL]; VAN DER ENT JAN, [NL]) 19 May 2005 (2005-05-19) page 8, line 13 - page 9, line 2, page 17, line 9 - page 18, line 12; figure 1a</td>
<td>10, 1-9, 11-18</td>
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<tr>
<td>Y</td>
<td>WO 01/71338 A (SHAW IND LTD [CA]; SIEBERT MARTIN ANTON, [CA]; PRENICE GARTH RODNEY [C] 27 September 2001 (2001-09-27) page 1, line 13 - line 18 page 4, line 10 - line 16; figures</td>
<td>1-9, 11-18</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C. See patent family annex

* Special categories of cited documents:

  - 'A' document defining the general state of the art which is not considered to be of particular relevance
  - 'E' earlier document but published on or after the international filing date
  - 'L' document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  - 'O' document referring to an oral disclosure, use, exhibition or other means
  - 'P' document published prior to the international filing date but later than the priority date claimed
  - 'T' later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
  - 'X' document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
  - 'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

Date of the actual completion of the international search

9 September 2009

Date of mailing of the international search report

04/11/2009

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2

NL - 2280 HV Rijswijk

Tel. (+31-70) 340-2040

Fax: (+31-70) 340-3016

Authorized officer

Savage, John
<table>
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<td>A</td>
<td>RAAD DE J A ET AL: &quot;MECHANIZED ULTRASONIC TESTING ON GIRTH WELDS DURING PIPELINE CONSTRUCTION* MATERIALS EVALUATION, COLUMBUS, OH, US, vol. 55, no. 8, 1 August 1997 (1997-08-01), pages 890-895, XP009006892 ISSN: 0025-5327 the whole document</td>
<td>1-18</td>
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<td>WO 0171338 A</td>
<td>27-09-2001</td>
<td>AU 3717601 A</td>
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Form PCT/ISA/210 (patent family annex) (April 2005)