Mechanized and Automated Ultrasonic Inspection

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Abstract. To find solutions for defect detection with ultrasound, different kinds of objects require different methods to achieve good verification. A lot of effects such as wall thickness of the part, surface conditions, geometry, material noise, etc. may depreciate the scan results and the possible system layout for the inspection system if not avoided.

There are important items to understand and to consider in the way of mechanized and automated Ultrasonic Inspection. Some of them are shown here.

1 Basic Definitions

The following table shows typical disambiguation’s for any ultrasonic application as with conventional or Phased Array ultrasound.

<table>
<thead>
<tr>
<th>Item</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Scan:</td>
<td>Ultrasonic RF-signal</td>
</tr>
<tr>
<td>B-Scan:</td>
<td>colour coded display of the Amplitude heights in consideration of the signal propagation time for the configurated inspection angels.</td>
</tr>
<tr>
<td>C-Scan:</td>
<td>Gated ultrasonic amplitude signals projected on the surface of the part as a scan grid</td>
</tr>
<tr>
<td>D-Scan:</td>
<td>Time of flight ultrasonic signals projected on the surface of the part as a scan grid</td>
</tr>
<tr>
<td>S-Scan:</td>
<td>colour-coded und angle corrected display of the amplitude heights of the configured inspection angle range of a Phased Array probe as sector in consideration of propagation time</td>
</tr>
</tbody>
</table>
Ultrasonic systems (examples)

For a series-accompanying ultrasonic inspection in immersion or contact technique with conventional ultrasonic or Phased Array technology various types of systems can be used. The following pictures exemplarily show 4 of them.
Application

1.1 Testing of thin and narrow stripes, small objects with defects at difficult areas – use of PHASED ARRAY Technology

Narrow stripes shall be tested for longitudinal cracks on the surface, in the volume and at the edges. During winding up the 500 m long strip, the UT test has to be done using an immersion technique.

Strip width: 8 - 10 mm  
Thickness: 1.2 - 2.0 mm  
Surface speed: 500 mm/s

Flaw size:
<table>
<thead>
<tr>
<th>Length</th>
<th>3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>1 mm</td>
</tr>
<tr>
<td>Depth</td>
<td>0.2 mm</td>
</tr>
</tbody>
</table>

Thin and narrow stripes, here shown a typical defect near the surface

The conventional technique uses a lot of immersion sensors and ultrasonic channels to inspect all areas with; (1) Dracula-, (2) Pulse echo and (3) Thru Transmission Mode in immersion.
The combination of Pulse Echo with Thru Transmission and Dracula technique together with $0^\circ$ and $45^\circ$ angle testing ensures that the defects parallel as well as $90^\circ$ to the surface can be found.

Using Phased Array Technology as an electronic scanning system saves a lot of UT – channels, probes and mechanical design.

Electronic scanning with a combination of Phased Array

The following 2 pictures show the Phased Array Zirkon of our equipment partner ZETEC as well as the corresponding data acquisition- and evaluation software UltraVision 3.
1.2 Testing of Carbon fiber reinforced plastics in Thru Transmission

Using the Thru Transmission Technique, it is important that the parallelism of the sensors is maintained all the time while following the part geometry as well as the vertical entrance of the beam into the part (90°). Small deviations cause loss of Thru Transmission signal, and may show the same red color in the C-Scan as defects.

Carbon fibre part between two ultrasonic probes

C-scan image with defect (delamination)

C-Scan image with the delamination defects in red color and the real part on the right side.
1.3 Inspection of extremely thin and small safety components on surface and volume cracks

Aluminum tubes for carriages

Wall thickness: 0.8 mm  
Part length: 50 mm  
Defect size:  
  Length: 3 mm  
  Depth: > 50 µm

Example 1: Defects such as cracks and small scratches can be found easily by ultrasonic scanning with shear waves in longitudinal direction.

Example 2: Defects such as cracks and small scratches can be found easily by ultrasonic scanning with shear waves in circumferential direction.
1.4 Inspection of a longitudinal weld with Phased Array Technology

Weld inspection of stainless steel pipes, with Phased Array Technology simulating the conventional technology following the rules of specifications.

![Schematic sketch – Phased Array probe on a part and sectorial scan (1 skip)](image)

Sectorial scans through the total weld each 1 mm along the pipe with all scanning angels from 35 - 70° (the picture on the right side shows a defect on the top of the pipe).

All sectorial scans can be reduced to certain angles (e.g. 45° and 70°) to fulfill the inspection specification (usually defined for conventional techniques) for the part. The result is a line scan, with all defects along the weld of the pipe (weld width 40 mm), in colours corresponding to the angle and type of probe, which has detected them.

![The following picture shows exemplarily a possible inspection system implementation for longitudinal welded pipes.](image)

Combined conventional and Phased Array probes on a pipe
**Effects on ultrasound**

Several conditions may effect ultrasound results while scanning:

- Grain size
- Geometrical reflections
- Electronic noise
- Surface conditions

In the following it is shown some of these effects.

### 1.5 Resolution of defects

The customer’s request is to detect defects > 0,3 FBH (flat bottom hole size). The C-Scans were made with a sensitivity of FBH 0,3 mm on 2,5 % screen height. The test was conducted with a 5 MHz probe (19 mm element diameter, 6 inch (150 mm) water path).

![Rotary part placed on a turntable under water](image)

The main red color reflects signals with 10 % screen height which corresponds to 0,6 mm FBH flaw size. In addition there are multiple reflection signals, with screen heights of 25 - 30 % (green signals) which correspond to about 1,0 - 1,2 mm FBH. But these were geometrical reflections of the underneath positioned turntable plate shown in the C-scan which might be misinterpreted as defects.

![C-scan – multiple reflection signals (green marked), produced by geometrical conditions as well as indications in the material which are much higher than the requested FBH of 0,3 mm](image)
Conclusion:

This material has reflections from grain which corresponds to a flat bottom hole of up to 1.2 mm. Under the general condition of a signal to noise ratio of 2 (6 dB), it is impossible to detect defects smaller than a flat bottom hole of 1.5 mm. The material grain needs to be of a higher quality or the detection of defects needs to have a lower acceptance limit, e.g. FBH 1.5 mm.

1.6 Disturbing geometrical signals

Beneath the grain signals of the C-Scan at the bottom there are 3 indications to be seen in the picture above. They are distinctive signals and because of the same appearance as well as the consistent position over the circumference of the part, they may not be defects. The TOF (time of flight) scan shows the signals much clearer.

![D-scan – much clearer picture as the C-scan](image)

The yellow signals have a tof=equal depth of 60 - 70 mm steel. These are caused by geometrical reflections of the chucks that hold the part on the turntable. Additionally it can be seen that the grain signals mainly have a time of flight depth of 120 - 160 mm steel. These geometrical ultrasonic indication varies with different part heights.

![C-scan – geometrical ultrasonic indication varies with different part heights](image)
The yellow background color in this picture (C-scan) is caused by the evaluation gate starting at about 40% screen height which corresponds to the yellow color (it was set higher because of the grain). Here the 3 indications are much longer and do not start at the bottom. They have a height of about 35 mm.

They are caused by the small grooves incurred during milling the surface of the part. The multiple grooves on the surface have generated a surface wave running down to the bottom and getting reflected at the area were the centering chucks of the turntable are touching the part (3 indications of the 3 symmetrical chucks).

![Schematic sketch – multiple grooves on the surface causing noise signals](image)

**Corrective action:**

Only smooth grinding of the surface with smooth sandpaper eliminates these “noise” signals.

1.7 **Influence of water level**

Another influence on the UT results could be created by the water level above the part. If the water level is too low, e.g. 40 or 50 mm, it could cause noise signals in the area of the C-Scan recording, even when the probe is placed in about 300 mm water depth, and parallel to the water level.

![C-scan with now noise](image) ![C-Scan with noise created by the low water level](image)

**Corrective action:**

It must be ensured that the tank is large enough so that a water level of at least 150 mm over the horizontal part surface could be used if noise signals appear.
1.8 Testing of stainless steel bars with the effect of side reflections and surface influences

Test piece with bore holes, drilled completely through the material, to show side wall effects

When scanning a part, a C-Scan view is expected that shows the part and its defects in the same way as seen. The bore holes in the part are shown as follows:

The five drilled holes should be seen as shown in the picture on the left side, starting at the left side going to the right side (as they are drilled totally through the material). But the result is different and shown in the picture on the right side. At the left and right side of the part, because of the side reflections at the edge of the part, the ultrasound picture shows the drilled holes, as they would be inside the material only and as the sides are closed. The beam on the sides is bended from the side to the inside of the material.

This effect has to be taken care of when measuring positions in a part, especially when the defects are at the edges of the part.

Another effect is shown with the next example.

When testing 10 bars in immersion scanned together with a short distance to each other, the C-scan above shows indications inside the bars. In the following C-scan it is shown by red marked circles. These indications are shown as if they are from inside of the material. But these were produced by very small air bubbles at the wall of the side of the part not on the top of the part. After eliminating these bubbles with a paint brush the bars were free of indications.
1.9 Influence of surface conditions

Small cracks of bad surface grinding cause ultrasonic signals in the C-Scan. Non parallel surfaces due to bad grinding of the parts instead of using the milling technique causes non-permitted attenuation of the back wall and changed sensitivity over the part scan area (see next picture). Even small waves from bad machining can influence the UT signals and cause non-permitted conditions.

Example 1: Small cracks of bad surface grinding cause ultrasonic signals in the C-Scan

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