Ultrasonic Inspection of Welds E-Book

This is not intended as a tuition course in how to use the equipment, although a few relevant aspects may be highlighted. Proper NDT training in accordance with appropriate standards is necessary before testing critical products.

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Essential Weld Technology

Welding is the process of joining materials together by applying sufficient energy to melt the surface of the material, allowing them to be joined together. Normally this will also involve the application of pressure to force the melted faces together, or the introduction of a similar filler material which melts and forms a 'weld pool' mixing with the materials to be joined.

Welding differs critically from soldering or brazing. In these processes a filler material is introduced which melts at a much lower temperature, forming only a surface bond with the parts. Steel can be brazed at a temperature of around 5-700˚C, whereas melting steel requires temperatures of over 1500˚C.

While there are many welding processes that generate these extremely high temperatures, the most common process for the joints we will consider is electric arc welding. There are three main methods of electric arc welding, each of which has its own characteristic properties and gives rise to its own unique defect types.

In general, this article is assuming that the metal being welded is a type of carbon steel. Welding of other metals is generally similar, but there may be minor differences in approach.

Metal – Inert gas (MIG) welding

An electric arc is struck between the base metal to be welded and a consumable solid metal wire which is fed in at a controlled rate, and the heat of the electric arc melts the metal which fills the weld preparation. A shielding gas (typically a mix of argon and carbon dioxide) is fed in around the welding electrode to exclude atmospheric oxygen and nitrogen.

Tungsten – Inert gas (TIG) Welding

An electric arc is struck between the base metal to be welded and a solid tungsten electrode. A consumable solid metal filler wire is normally fed in at a controlled rate, and the heat of the electric arc melts the metal which fills the weld preparation. A shielding gas (typically a mix of argon and carbon dioxide) is fed in around the welding electrode to exclude atmospheric oxygen and nitrogen. For thin metals, TIG welding can be used without additional filling – just melting the base metal together – but this is not normally used in settings where ultrasonic testing is applicable.

Submerged arc (SAW) welding

An electric arc is struck between the base metal and a tubular filler wire which is cored with a suitable flux. The flux melts and floats on top of the molten metal, excluding the atmosphere. Alternatively, the welding filler material may be a solid wire or strip with the flux applied separately. Because the welding arc is normally hidden beneath the flux material, SAW welding is frequently an automatically controlled process.

Weld preparation

Regardless of process, a weld will normally be built up in multiple passes as shown in Figure 1. The initial 'root pass' (1) holds the joint together; in most cases the next pass should be done before the weld has cooled significantly, and subsequent passes allow the weld to be built up to its final geometry.

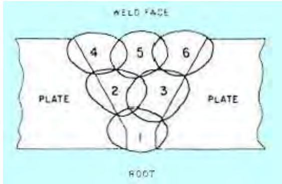


Figure 1: Building up weld layers

To create an effective and strong weld, it is normally necessary to prepare the edges to be joined. This performs a dual function: cleaning the site of any oxide or contamination and shaping the edges to allow the weld to be built up in a way that provides the maximum strength. Where maximum joint strength is not critical, simple fillet welds with minimal preparation are possible as shown in Figure 2.

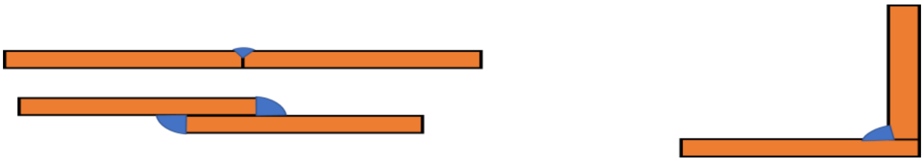


Figure 2: Fillet Welds

Fillet welds contain large areas of adjacent metal surfaces that are not welded. This makes them difficult to test ultrasonically, as we are trying to distinguish between slightly different echoes in similar locations. It is much easier in a solid weld, where any echo in the region of interest is likely to be a defect. Fortunately, fillet welds are seldom used in critical applications where NDT is required.

Groove welds

In critical welds, material will be removed for the full depth of the metal plate, allowing the weld to be evenly built up throughout the full thickness. Typically in thinner plates (maybe less than 25 millimetres) this will be done from one side; for thicker materials, it is normal if possible to build up the weld evenly from both sides, to minimise stress and to remove as little material as possible.

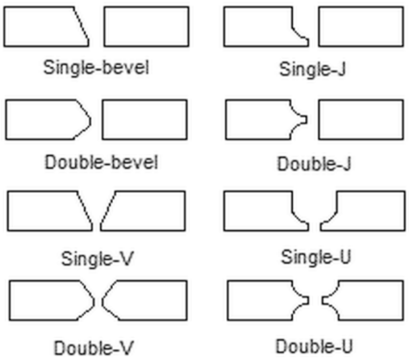


Figure 3: Typical Weld preparations

Typical weld preparation configurations are shown in Figure 3. Perhaps the most common weld configuration is a single-V preparation, with the faces prepared by grinding to 30 degrees from vertical. Thicker materials, especially where access is only possible from one side, may use relatively narrow U or J preparations. This minimises the amount of material removed and the amount of weld filler metal that must be used.

Modern ultrasonic instrumentation typically allows the weld configuration (or at least the material thickness) to be entered, to aid the operator in identifying where indications have come from. This can be critical in analysing the likely source of the reflection; for example, any indication in the centre region of the weld is likely to be a defect, but indications from one side of the material or the other might be due to the material geometry. It is important that the operator has the necessary skills to understand which is which.

Typical weld defects

Some defect types are specific to particular weld processes, but not all. Some common defect types are:

A. Geometric defects:

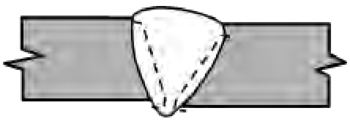


Figure 4: Misalignment

The metal on one side of the weld is higher than the other. This is often caused by careless fit-up of the metal before welding. While it may not necessarily impact the strength of the weld, it can cause problems in ultrasonic inspection and can be confused with other defect types. This type of defect is commonly checked for using a mechanical gauge.

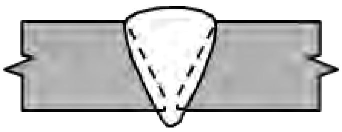


Figure 5: Excessive penetration

Excessive penetration is normally caused by inaccurate weld preparation (e.g. too large a gap) or excessive heat in welding. while this does not reduce the weld strength, it can cause problem in some applications, especially in pipe welds where it can interfere with flow.

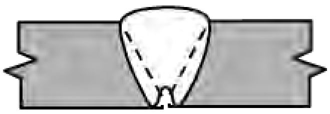


Figure 6: Root concavity

Root concavity (or lack of penetration) can be caused by poor preparation, excessive welding speeds, or excessive heat during the second weld pass melting the root. It may cause the weld to be weaker than expected.

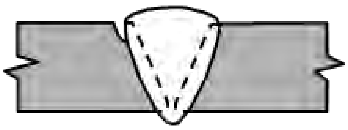


Figure 7: Undercut

An irregular groove at one side of weld is often caused by insufficient fill material or excessive speed. Some level of undercut is usually acceptable.

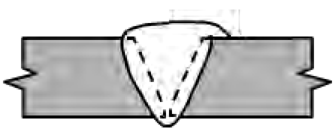


Figure 8: Overlap

Unbonded metal at the side of the weld can be caused by poor technique, such as an excessive weld pool or a cold or contaminated surface.

B. Porosity and inclusions

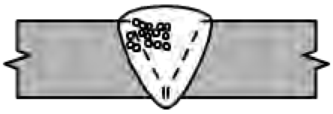


Figure 9: Porosity

Porosity is caused by gas being trapped in the weld. This may come from a variety of sources, such as contamination of the weld or base metal, moisture, or poorly controlled shielding gas. Porosity can be random or evenly distributed and can involve large pores or a cluster of small ones.

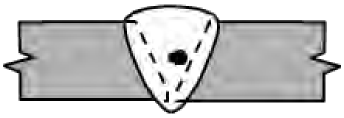


Figure 10: Inclusions

Solid material in the weld can come from a variety of sources, often characterized by the weld process. A SAW process might have inclusions of slag or flux, while damaged TIG welding tips might lead to tungsten inclusions. Oxide inclusions are often more irregularly-shaped than pores, which tend to be 'bubbles'.

C. Lack of fusion defects

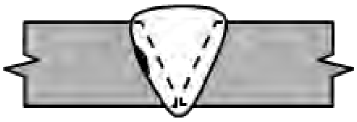


Figure 11: Lack of side-wall fusion

Lack of fusion can appear anywhere in the weld, but root and side-wall fusion defects are the most common. They can be caused by poor control of the welding process, by contamination, or by poor preparation of the base metal. Because defects on the 'fusion face' can leave a flat reflecting surface, it is often critical to design an inspection approach that can detect it.

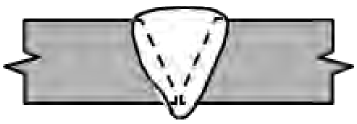


Figure 12: Lack of root fusion

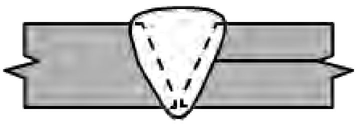


Figure 13: Delamination

Not a weld defect as such, delaminations are caused by a lack of fusion within the base metal – commonly by slag inclusions which have been rolled very flat. Not only do they weaken the joint region, they may prevent proper ultrasonic examination: sound will be reflected within the top part of the material, and no energy will reach the lower part of the weld. This can result in a false negative, with serious defects being unreported. It is therefore normal to do a lamination check with a zero-degree probe, to ensure the metal registers the expected thickness before the weld is scanned.

D. Cracks

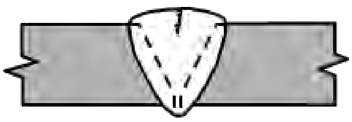


Figure 14: Longitudinal crack

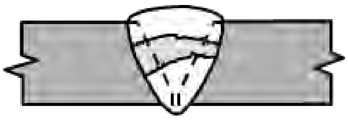


Figure 15: Transverse crack

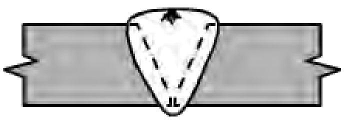


Figure 16: Crater crack

Cracks can be produced during the welding process, or later due to stresses. Cracks of any size are normally unacceptable because they tend to concentrate stress and propagate easily.

Cracks can frequently be caused by cooling the weld too fast after the welding process, or by incorrect heating before or after the welding process. Transverse cracks are normally the result of longitudinal stresses in the weld. Crater cracks (or star cracks) can initiate from an abrupt weld termination / restart.

Cracks can often occur in the heat-affected zone (HAZ) near the weld.

Normally cracks of any kind must be ground or gouged out and rewelded.

Key points about ultrasonic inspection of plate welds

It is important to understand the following points:

- Most, if not all, welding inspection standards require that the operator identify the type, size and severity of defect according to appropriate criteria, thus accurate measurements and calibration are essential.
- It is important that the inspector understands the weld geometry and technology, to allow the best possible assessment of defect type, and to identify 'artefacts' – reflections from the geometry of the weld or structure.
- Sometimes ultrasonic inspection alone will not give a definite assessment of defect type; for example, a lack of root fusion and a root crack can look similar and may have to be assessed as a 'root defect'. Defects on the top surface may be hard to distinguish from irregularities in the weld crown. It is quite common for ultrasonic inspection to be combined with other methods.

  A full visual examination and the use of appropriate measuring gauges to identify issues such as misalignment should always be carried out before the ultrasonic examination.

- As mentioned earlier, delaminations in the base metal plate can prevent the sound from reaching part of the weld area. This is not always obvious. It is standard practice to carry out a zero-degree inspection to confirm the metal thickness and identify any delaminations (which will cause the metal to appear much thinner).
- Inspection of welds which have been in service is quite different from inspection of new welds. Normally, one should be able to assume that any

manufacturing defects such as lack of fusion, porosity or inclusions will have been found when the weld was originally inspected, so these defects should not be present. In-service inspection will usually be looking for cracking or corrosion defects. In many cases, other NDT methods such as magnetic particle inspection or electromagnetic techniques (eddy current or ACFM) may be more appropriate.

- Normally a weld should be inspected from both sides, as the orientation of defects may make them difficult or impossible to detect from one side. A structure that does not allow this may make it impossible to eliminate the possibility of some orientations / positions of defects, so this should be considered at the design phase. An example with a pipe flange is shown in Figure 17.

  Note that this was less of an issue when using X-ray inspection, and hence some existing designs with flanges and elbows are unsuitable. Phased array inspection will often give a better probability of identifying defects in 'unfavourable' locations because an image is produced.

  To reduce this problem, fittings (such as flanges) are often made with a sufficient length of 'stub' to create a gap between the weld and the fitting.

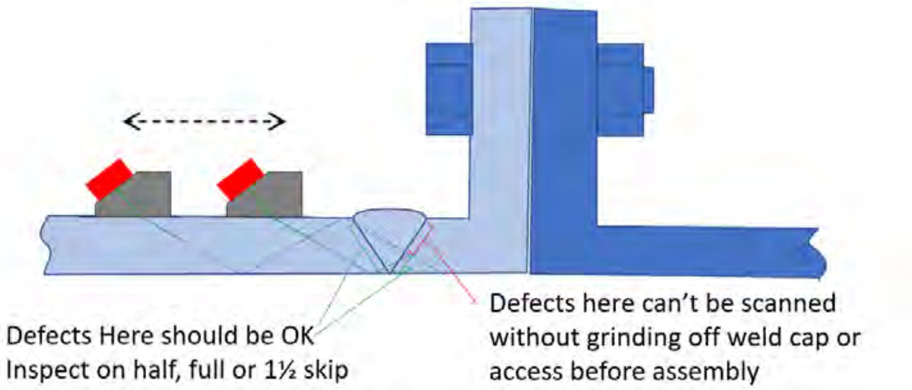


Figure 17: Example of weld location making inspection difficult

- Cracks may also occur in the heat-affected zone (HAZ) either side of the weld, particularly if it is subjected to stress while cooling. Normally an inspection should cover a region several millimetres beyond the melting zone of the weld.

Standards

Many standards organizations issue documents applicable to ultrasonic weld inspection.

Appendix A shows a list of the BS/EN/ISO standards applicable to this in the UK. There are many other organizations who also issue standards. Individual industries or companies may also use their own internal standards.

There are several different types of relevant standards which can be loosely categorized as:

- ‘Background standards’ – equipment characterization, operator qualification, terminology etc.
- ‘Instructional standards’ – general guidance on how to carry out a particular inspection technique.
- ‘Acceptance standards’ – what defects must be rejected to use a welded structure for a particular application. These requirements may often be contained within general material or product standards, rather than being NDT standards as such. Standards sometimes combine details of the method to be used with acceptance criteria

A particular standard that will be frequently met, and is discussed later, is the American Welding Society (AWS) Structural Welding Code for Steel, AWS D1.1. This gives great detail about acceptable design and construction of welded structures, of which ultrasonic NDT is only a very small part. The NDT procedures are very prescriptive as to what equipment is used, how indications are evaluated and how they are reported. Modern equipment typically provides software tools to assist with evaluation and reporting according to the AWS requirements. For more information, refer to the standard and to specific equipment manuals.

A common standard for weld inspection is ISO 17640, most recently updated in 2018. This replaces the older EN 1714, which itself replaced the German standard DIN 54125 and the British standard BS 3923.

It references the following standards:

- ISO 5577, Non-destructive testing — Ultrasonic testing — Vocabulary
- ISO 9712, Non-destructive testing — Qualification and certification of NDT personnel
- ISO 11666, Non-destructive testing of welds — Ultrasonic testing— Acceptance levels
- ISO 16810, Non-destructive testing — Ultrasonic testing — General principles
- ISO 16811, Non-destructive testing — Ultrasonic testing — Sensitivity and range setting

- ISO 16826, Non-destructive testing — Ultrasonic testing — Examination for discontinuities perpendicular to the surface
- ISO 17635, Non-destructive testing of welds — General rules for metallic materials
- ISO 23279, Non-destructive testing of welds — Ultrasonic testing — Characterization of discontinuities in welds
- EN 12668 (all parts), Non-destructive testing — Characterization and verification of ultrasonic examination equipment

Clearly, a lot of reading can be required to establish what is needed for a particular application, although in practice there is a lot of duplication between these standards.

Evaluation methods and criteria

Weld defects may be evaluated either using an amplitude-based method (such as comparing the strength of reflection to a standard reference reflector such as a hole of known diameter), or by direct dimensional measurement using a technique such as TOFD. Typically, acceptance standards specify a maximum length (which may be zero, meaning no defects acceptable) for defects of a particular type and size / reflection strength.

Amplitude-based methods require compensation for the reduction in signal with distance.

This is a result of two distinct factors:

a) Geometric spread of energy; close to the probe this is determined by the probe size and frequency, and at a distance the response approximates to an inverse square law.
b) The loss of energy within the material itself, primarily due to scattering effects. This normally increases greatly at higher frequencies.

The idea is to compensate so that the measured severity (the strength of the reflection) correlates to the size. This compensation may be done in several ways.

DAC

To create a DAC (Distance amplitude correction) curve, the strength of an echo from reflectors of the same size at different distances is measured and a curve fitted. Most modern equipment contains software to enable this. Historically, it was achieved by drawing on the flaw detector display using a Chinagraph pencil.

Once the curve has been calculated, the software can also create subsidiary curves, drawn at a certain dB ratio above or below it. This allows the use of different thresholds for calibration and inspection.

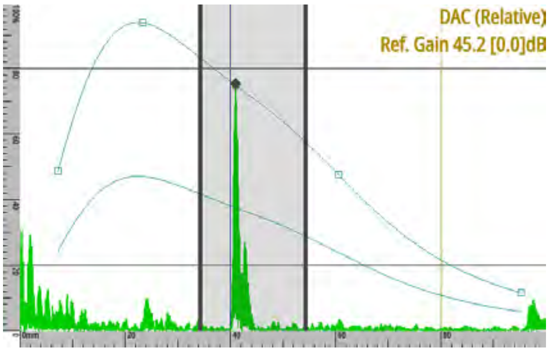


Figure 18: Creation of a DAC curve

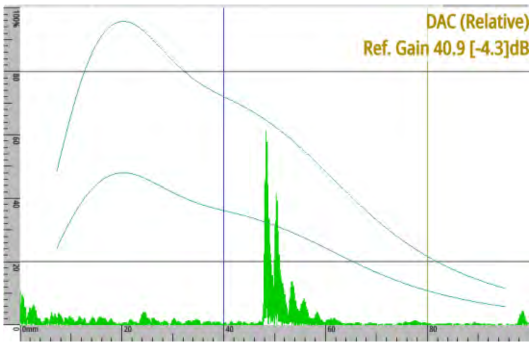


Figure 19: DAC curve used for echo amplitude evaluation.

TCG

TCG (Time controlled gain) achieves the same result as DAC, by rapidly varying the gain of the equipment so that reflections at different distances are corrected to have the same amplitude. Many modern instruments can convert between DAC and TCG without recalibration.

TCG has the advantages that it is easier to interpret small signals, which with DAC might be only a few percent of screen height. TCG is also the only method that can be easily applied where defect detection is done automatically, or by conversion to a colour palette, this includes B-Scan equipment, C-scan equipment and various phased array displays.

Figure 20 shows TCG in use on a Sonatest Wave instrument, Note that:

a) The curve shows the gain change; unlike with DAC or DGS, it does not represent a threshold.
b) The noise level will increase toward the right side of the screen because the gain is higher.

DGS

DGS (Distance-Gain-Size, also known by its German acronym AVG) is a special type of calculated DAC curve, based on a theoretical prediction of echo amplitudes from the probe, based on its near-field length and effective diameter. It has the advantage that the operator only needs to calibrate at a single amplitude point (typically a back-wall echo or side-drilled hole), so does not need to carry around heavy test pieces.

The DGS method has the disadvantage that it can only be used with a small range of 'well-behaved' probes, where the sound field pattern is consistent and matches the theoretical model. Issues such as transfer loss due to rough surfaces and material attenuation must also be well understood if accurate evaluation is to be obtained.

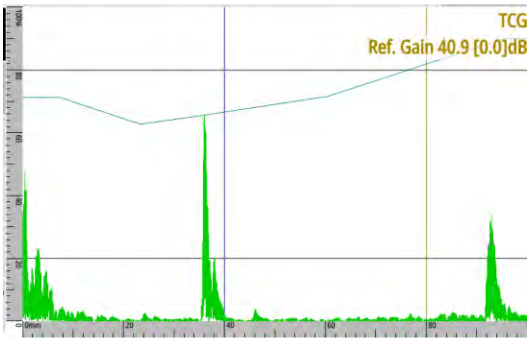


Figure 20: TCG in use.

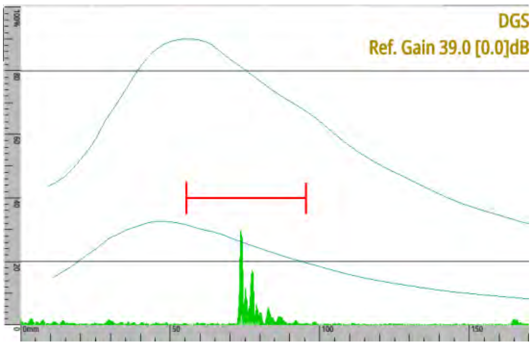


Figure 21: DGS in use

Procedure specific methods

A typical example here would be the AWS D1.1 defect evaluation approach. This uses a very prescribed setup, and then applies an attenuation factor in dB proportional to the sound path length. This is simple to apply on basic equipment and requires limited calibration. Most modern equipment can calculate the AWS 'indication rating' automatically.

- Covers groove welds in material with thickness between 8mm and 200mm inclusive
- Angle beam transducers must be 2 to 2.5MHz, 15 to 25mm long, 15 to 20mm high. A 5/8in (16mm) square is most used
- Calibrate using the 1.6mm hole in an IIW block– gain required is recorded as (b)
- Adjust gain on defect indication – gain required is (a)
- Calculate the attenuation factor (c), which is sound path distance in inches, minus one, multiplied by two
- Then calculate an indication rating (d) , which is a – b – c
- Measure length indication and evaluate according to an appropriate table
- Refer to the AWS standard for full details

Table 6.2
UT Acceptance-Rejection Criteria (Statically Loaded Nontubular Connections) (see 6.13.1)

Discontinuity Severity Class	Weld Size* in in. [mm] and Search Unit Angle										
	5/16 through 3/4 [8–20]	> 3/4 through 1-1/2 [20–38]	> 1-1/2 through 2-1/2 [38–65]			> 2-1/2 through 4 [65–100]			> 4 through 8 [100–200]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+5 & lower	+2 & lower	–2 & lower	+1 & lower	+3 & lower	–5 & lower	–2 & lower	0 & lower	–7 & lower	–4 & lower	–1 & lower
Class B	+6	+3	–1 0	+2 +3	+4 +5	–4 –3	–1 0	+1 +2	–6 –5	–3 –2	0 +1
Class C	+7	+4	+1 +2	+4 +5	+6 +7	–2 to +2	+1 +2	+3 +4	–4 to +2	–1 to +2	+2 +3
Class D	+8 & up	+5 & up	+3 & up	+6 & up	+8 & up	+3 & up	+3 & up	+5 & up	+3 & up	+3 & up	+4 & up

* Weld size in butt joints shall be the nominal thickness of the thinner of the two parts being joined.

Notes:
1. Class B and C discontinuities shall be separated by at least 2L, L being the length of the longer discontinuity, except that when two or more such discontinuities are not separated by at least 2L, but the combined length of discontinuities and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B or C, the discontinuity shall be considered a single acceptable discontinuity.
2. Class B and C discontinuities shall not begin at a distance less than 2L from weld ends carrying primary tensile stress, L being the discontinuity length.
3. Discontinuities detected at "scanning level" in the root face area of CJP double groove weld joints shall be evaluated using an indicating rating 4 dB more sensitive than described in 6.26.6.5 when such welds are designated as "tension welds" on the drawing (subtract 4 dB from the indication rating "d"). This shall not apply if the weld joint is backgouged to sound metal to remove the root face and MT used to verify that the root face has been removed.
4. ESW or EGW: Discontinuities detected at "scanning level" which exceed 2 in. [50 mm] in length shall be suspected as being piping porosity and shall be further evaluated with radiography.
5. For indications that remain on the display as the search unit is moved, refer to 6.13.1.

Class A (large discontinuities)
Any indication in this category shall be rejected (regardless of length).

Class B (medium discontinuities)
Any indication in this category having a length greater than 3/4 in. [20 mm] shall be rejected.

Class C (small discontinuities)
Any indication in this category having a length greater than 2 in. [50 mm] shall be rejected.

Class D (minor discontinuities)
Any indication in this category shall be accepted regardless of length or location in the weld.

Scanning Levels	
Sound path[b] in in. [mm]	Above Zero Reference, dB
through 2-1/2 [65 mm]	14
> 2-1/2 through 5 [65–125 mm]	19
> 5 through 10 [125–250 mm]	29
> 10 through 15 [250–380 mm]	39

[b] This column refers to sound path distance; NOT material thickness.

Figure 22: AWS D1.1 for angle beam testing in brief

Inspection of welds using mono-element ultrasonic flaw detectors

Once mechanical checks and a delamination check have been carried out, an ultrasonic weld inspection will usually be conducted in several stages:

Critical root scan

Defects at the root of a weld – such as cracks, lack of penetration or 'undercut' – can very quickly propagate and weaken a structure. They must therefore be found with a high reliability. They may also be difficult to distinguish from the 'normal' reflection from the weld bead. A careful scan with a shear wave probe at a fixed distance (a magnetic ruler or similar guide is helpful) from the weld will allow root defects, which normally show up 'ahead' of the root signal, to be distinguished. Often the weld bead signal will be small, but this cannot be assumed.

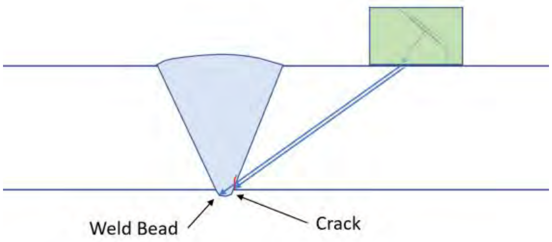


Figure 23: A critical root scan

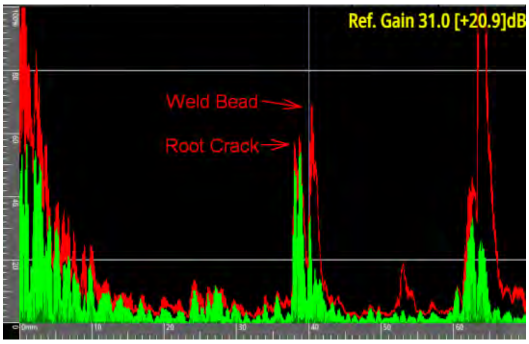


Figure 24: Weld bead and root crack indications on the WAVE

Inspection from both sides will normally assist the inspector in distinguishing between cracks and other issues such as lack of penetration. With a crack the root bead will be seen from one side, with lack of penetration the signal should be similar from either side.

Weld body/fusion face Inspection

Normally, the weld body and the fusion face will be inspected by moving the probe between the position used for root defect inspection and the position at which the 'full skip' (i.e. reflected once from the lower surface of the plate) beam intersects the top of the fusion face. The probe angle used should match the weld bevel angle (so a 60 degree probe should be used for a 30 degree weld angle). This should find defects in the body of the weld and in the 'near' fusion face.

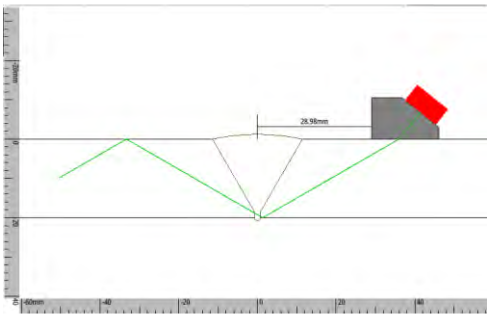


Figure 25: Scan at root

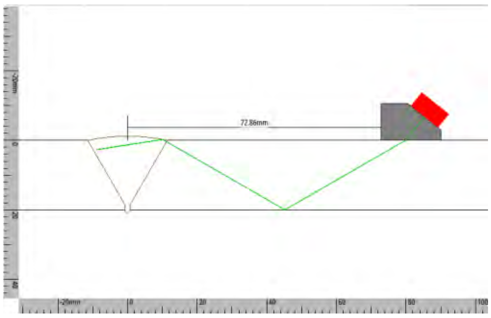


Figure 26: Scan at edge of weld cap.

Note that, because of the unfavourable angle, this will not give a strong signal (if any) from a lack of fusion on the far fusion face. The inspection should always be repeated from the far side. A 'half-skip' or 'third-leg' inspection may give partial coverage of this region, but this is not recommended if alternatives exist. Reflections from the weld crown will be erratic unless it has been ground flat.

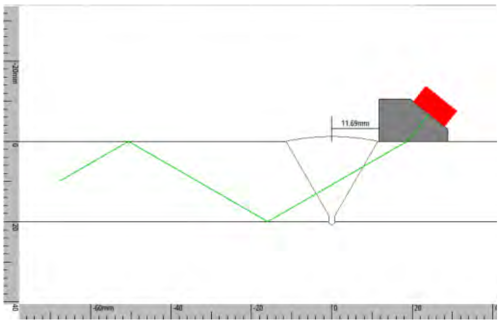


Figure 27: Scan of 'far side' extent limited by weld cap

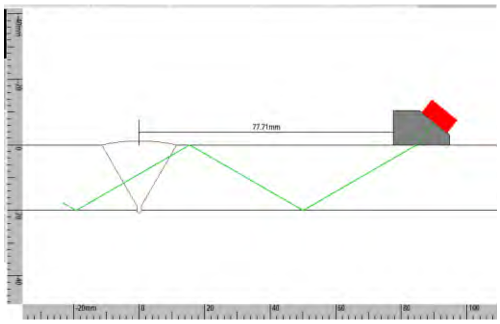


Figure 28: 'Third-leg' scan - only a bit further up

To scan a weld, the probe should be moved between these two positions in a ‘zig-zag’ or ‘raster’ pattern along the weld. Doing this consistently takes skill and practice.

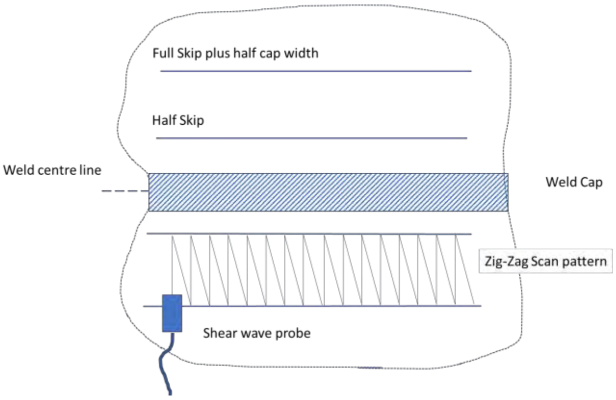


Figure 29: Typical scanning pattern for weld

Scan for transverse defects

Where the weld cap has been ground flat, this can be done using a single probe scanned along the weld centreline. Where the weld has not been ground, the probe should be scanned along to one side – or two probes, one either side, used in a 'pitch-catch' configuration The scan should be done from both directions and, in the case of a single probe from the side, both sides.

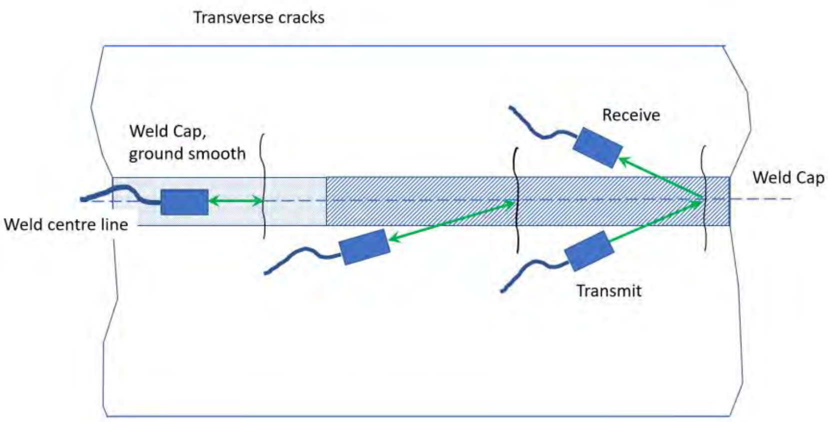


Figure 30: Inspection options for transverse cracking

Double-V and more complex shaped welds

The scan distance should cover from the half-skip to centre-line, back to the full skip to edge of the upper weld crown (plus HAZ) as shown in Figures 31 and 32.

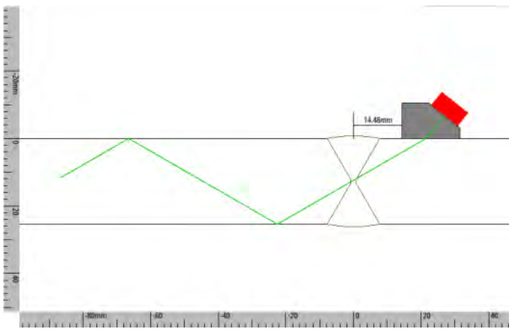


Figure 31: Nearest scan extent for double-V weld

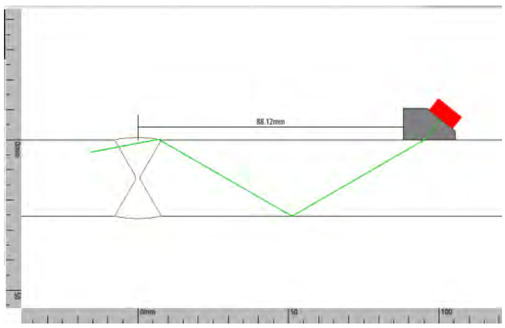


Figure 32: Furthest scan extent for double-V weld

Special attention should be paid to the weld centre region; in particular, if the preparation has a significant vertical region (shown slightly exaggerated in Figure 33), this should be tested with a high angle (70 or 80 degree) probe, or ideally with a tandem probe arrangement. The tandem setup will normally need a suitable fixture to keep the probes at the correct distance.

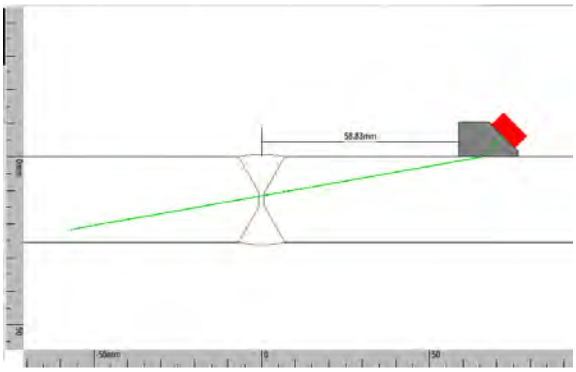


Figure 33: Single probe inspection for root defects

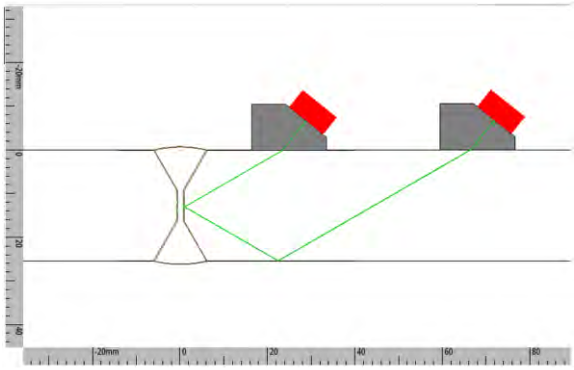


Figure 34: Tandem probe inspection for root defects

Complex weld shapes need to be evaluated on a case-by-case basis, ensuring that the full body of the weld is inspected and that the probe angle is suitable for location of smooth lack of fusion defects.

Compression mode probes

For carbon steel, inspection is almost always done using a shear wave mode probe. For some materials, particularly austenitic steels, shear waves do not propagate very well; for these, a longitudinal mode (compression wave) probe will give better results. To improve signal to noise ratio, a dual element probe is often used.

Figure 35: Twin crystal compression angle probe

Inspection of welds using TOFD

TOFD (Time of Flight-Diffraction) is a geometric diffraction technique. The time taken by the signal diffracted from the tips of a discontinuity is measured; this allows calculation of the path length, and thus, by trigonometry, the depth.

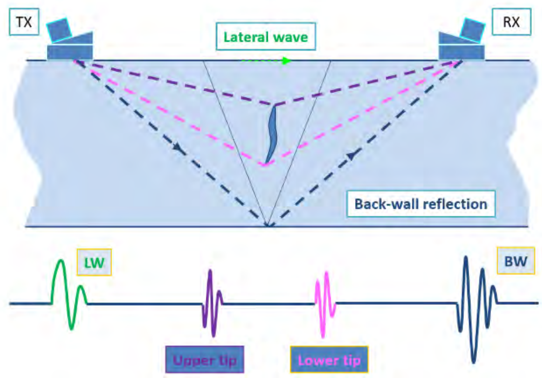


Figure 36: TOFD measurement

Key points about TOFD:

- We are primarily looking at diffracted signals, rather than reflected ones. These signals are much weaker and as long as they can be detected, the amplitude is not important – only the timing.
- The probes are designed to give a wide spread of energy to cover the area of interest, rather than a narrow beam, and they are typically much smaller in diameter than other probe types. A 5MHz 6mm probe, or a 10MHz 3mm diameter probe, are typical. Probes are usually supplied with separate wedges, allowing the correct frequency/diameter/angle combination to be selected.
- Since the signals are small – both because they are diffracted, and because a wide beam is used – high gain is needed, and often a preamplifier will be required.
- To cover thick materials, the beam spread and sensitivity of a single probe pair may still not be enough to give optimal results. For material thicker than 30mm or so (depending on the standard applied), two or more probe pairs at different frequencies or angles may be required.
- All Sonatest phased array instruments (Prisma, veo, veo+) can be configured to carry out two simultaneous TOFD scans. The instruments include tools for setting up the scan (see Figure 37) as well as for measurement / evaluation of indications.
- Because we are making accurate measurements, precision is essential. The probes must be held in a rigid support, with position tracked by an encoder.
- Offline assessment is normally required.
- Hyperbolic cursors on the instrument assist in measuring the precise dimensions of the indication, allowing assessment.

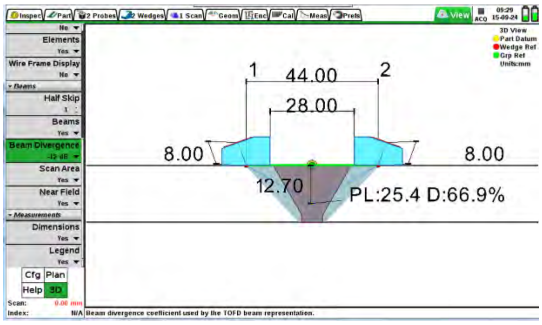


Figure 37: Setting up a TOFD scan on the veo

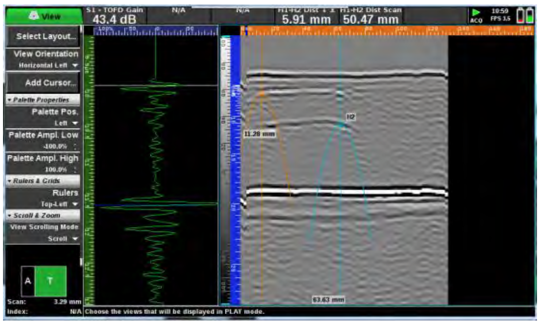


Figure 38: Indication measurement using hyperbolic cursors

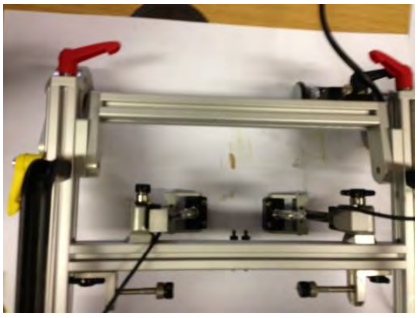


Figure 39: Scanner with TOFD probes

Detailed use of TOFD and evaluation of indications is outside the scope of this document.

Please refer to appropriate standards and training materials.

Inspection of welds using phased array instruments

The term ‘phased array’ (PA) is used to refer to several different related techniques:

1. ‘Standard’ beamforming phased array, where probe element firing delays are used to create an ultrasonic beam with a specific angle, position, and focus. This can be rapidly changed to create a sequence of scans, which can be assembled to form a ‘picture’.
2. Full Matrix Capture (FMC), where the sequence fires one element at a time, collecting data on all the other elements. This data can then be combined to produce an image using a variety of approaches. Most commonly, the Total Focusing Method (TFM) is used, which as the name implies, creates an image that is ‘in focus’ at all points. One of the key advantages of FMC/TFM is that discontinuities are interrogated from a variety of directions. This allows a more accurate representation of the shape and orientation of defects to be determined. The main disadvantages are that it tends to be slower and that it collects massive quantities of data.
3. ‘Real time’ TFM, where the above process is done live. This can give quick and accurate results but relies on the operator selecting the correct image reconstruction options at the time of testing. There is normally no ability to ‘re-analyse’ with different options.

This document will primarily deal with beamforming PA, which is well established as an inspection method. At present, the process of developing agreed standards for TFM methods has only just started.

Key points about phased array for weld inspection:

a) The physics of PA inspection are identical to mono-element ultrasonic inspection. The advantages are:
    a. Ability to produce multiple angles.
    b. Speed – it can usually replace or reduce the need for scanning at multiple distances from the weld. Often, a single scan along a weld at several centimetres per second is acceptable.
    c. Ability to save data and produce reports with images is included in most equipment
    d. Because of the imaging capability, interpretation can be easier.
b) A sound beam still needs to be produced at a suitable angle to get a reflection back to the probe from possible defects.
c) Phased array probes tend to be larger, so in some cases there is a compromise between access and the ideal probe characteristics. Probes similar in size to conventional ultrasonic probes are available,
d) The use of a scanner / encoder setup is strongly recommended. It is possible to scan manually and investigate indications manually – and this can still gain a speed advantage over manual UT – but most of the potential advantages of phased array require precise logging of position.

Approaches to phased array scanning

1. Single sector scan

The simple sector scan, with a single scan setup covering a range of angles, is shown in Figure 40. This image is created using the UT studio+ software, supplied with all Sonatest phased array instruments.

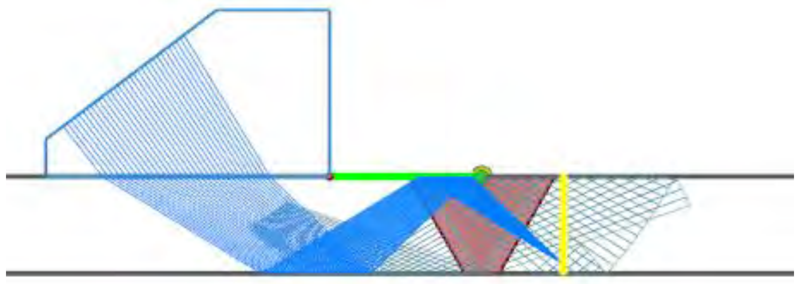


Figure 40: Phased array sector scan of weld

In Figure 40 we see beams at a range of angles (from 50 to 70 degrees at 1-degree increments), with the element contributions to the 50-degree beam. The yellow line shows the focus for each beam angle. Here we have placed the focus just beyond the heat affected zone (shown in red).

The software allows us to 'unwrap' the part to showing each reflection skip separately as shown in Figure 41. This is often much clearer:

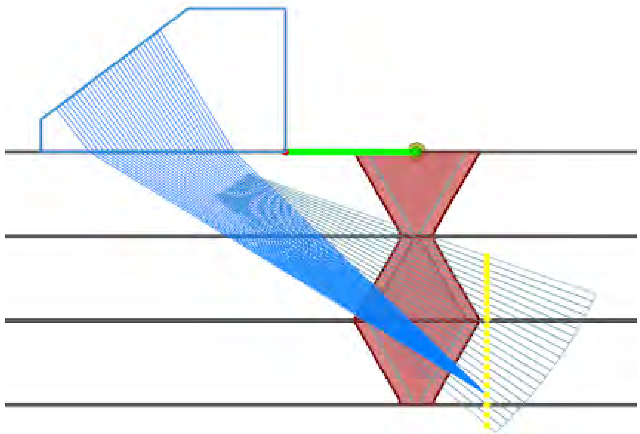


Figure 41: Phased array sector scan as in the previous figure, shown with reflections in part 'unwrapped'

For mono-element ultrasonic testing, a maximum of ±5° off normal to the fusion face is recommended. With phased array the images are clearer, and we can (subject to code) relax this slightly. In Figure 41we see that the beam from 50 to 70 degrees just reaches the extremes of the face at full skip, and again on the 'third leg'.

2. Dual sector scan

As elsewhere, it is recommended that the weld is scanned from both sides. With the veo+, two probes and a suitable scanner, this scan be done in a single pass and the data recorded into a single file, This increases the inspection speed, and allows a single report to combine the scans from either side.

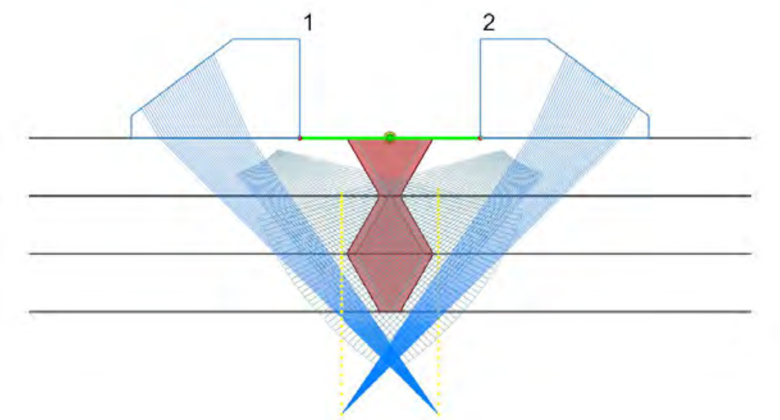


Figure 42: Dual sector scan of weld

3. Linear scan

Alternatively, a linear scan at the weld bevel angle can be used to give an equivalent test to a mono-element raster scan. The disadvantage is that even a standard 64 element (X3 or equivalent) probe may not be long enough to cover the full weld bevel in a single scan. A longer and larger pitch probe can be used, but this may be bulky, and may be less suitable for a sector scan due to its inferior beam steering characteristics.

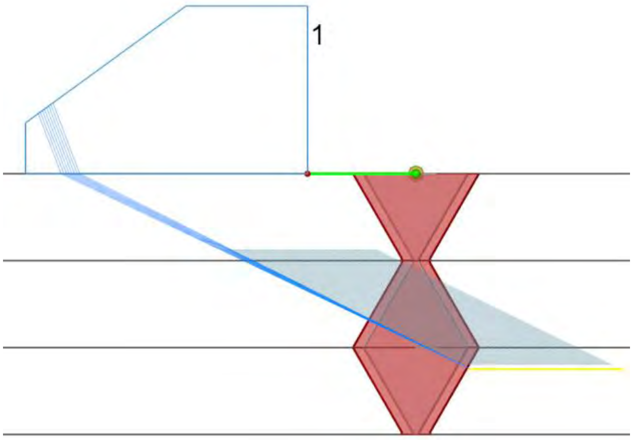


Figure 43: Linear scan of weld

4. Multiple scans

We can use a dual probe setup to carry out simultaneous linear and sector scans, from both sides, providing improved probability of detection into a single record.

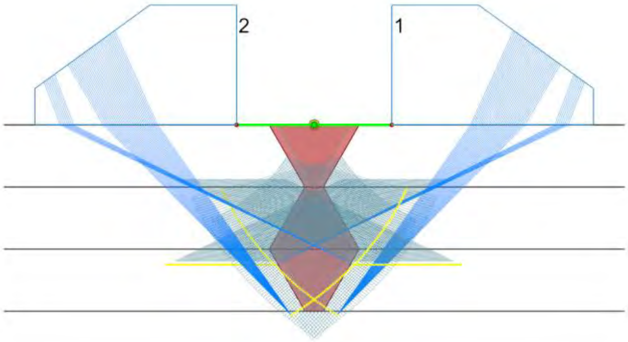


Figure 44: Dual linear and sector scans of a weld

5. Combining phased array and TOFD

Both theoretical and experimental studies show that combining phased array and TOFD scans greatly increases the reliability of weld inspection. This stems from two factors:

a) They are very different methods, so the statistical effects can be treated as independent. For example, if a particular phased array inspection has an 80% probability of detection (so a 20% chance of missing a defect) and a TOFD inspection also has an 80% POD, combining the two means that 20% chance of failure is itself multiplied by 20% - leaving only a 4% chance of missing the defect, and a 96% probability of detection.
b) The weaknesses of the two methods are complementary. For example, where TOFD can miss defects near the surface, PA is good at catching them; and where PA can miss unfavourably oriented defects (which is why we test from both sides), TOFD is in turn stronger.

The veo+ allows us to set up multiple scans. In Figure 45 we show a sector scan and a linear scan from each side, plus a TOFD scan.

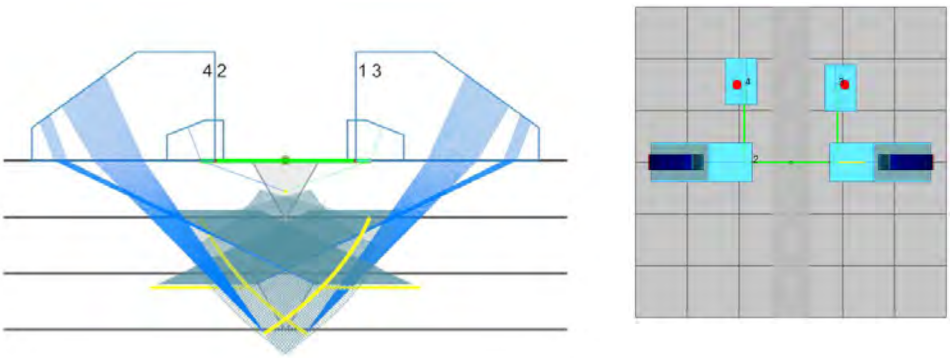


Figure 45: Combining Phased array and TOFD; top view of typical probe arrangement shown

While this might be considered overkill and running five scans simultaneously can reduce the maximum acquisition speed, it is an appropriate compromise for critical applications.

6. Check scans

With a multiple probe setup, it can be useful, especially for automated scans, to add a simple zero degree scan to check the back wall location and coupling. An additional scan can be allocated to this on each probe; generally, this can be a very coarse scan, so that it uses minimal extra scanning time.

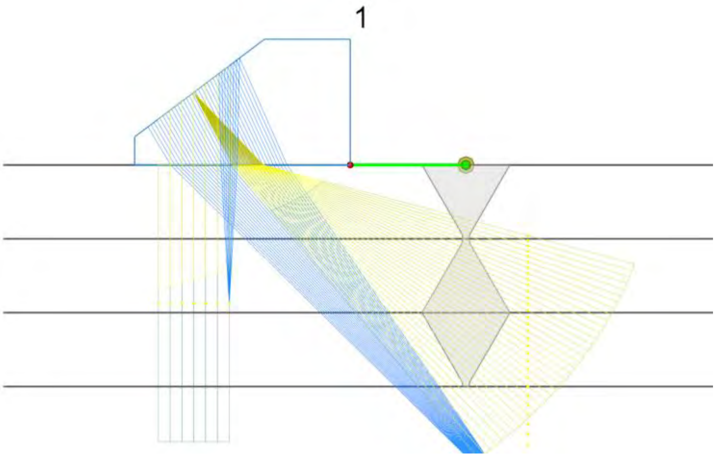


Figure 46: Use of a coupling check scan

While creating a zero-degree scan using a high angle wedge is far from optimal, the performance is sufficient to provide a coupling check and verification of back wall for quality control purposes.

Data acquisition

As mentioned earlier, to collect acceptable data it is essential that the instrument is set up correctly and the probe is manipulated correctly.

If the intention is to do a simple good/bad scan and mark defects for later action, a manual scan without encoding or recording may be acceptable. The practice here is to scan carefully along the weld, normally with a magnetic ruler or similar for guidance; indications are marked for investigation and, after scanning a length, the individual defect indications are investigated, measured, marked, and written down.

When submitting reports of critical welds for a customer or client, best practice is to supply images and possibly datafiles of relevant scans, even where no defects are found. The veo series allows the client to use the free UTstudio viewer software to review files if desired.

Prior to making any recording the following approach should be taken:

- Ensure the equipment is set up properly; ensure all probes are in good condition, check coupling in any wedges etc.

- Check calibration on all channels.

- Set the instrument display to give at least one scan which shows any missing data points (usually a top view or B-scan). Missing data is normally a sign that the probe is being moved erratically or at excessive speed. Check also that the pulse repetition frequency (PRF) on one or more channels is not set too low, causing that scan to take too long. Missing data will only be visible if an encoder is used.

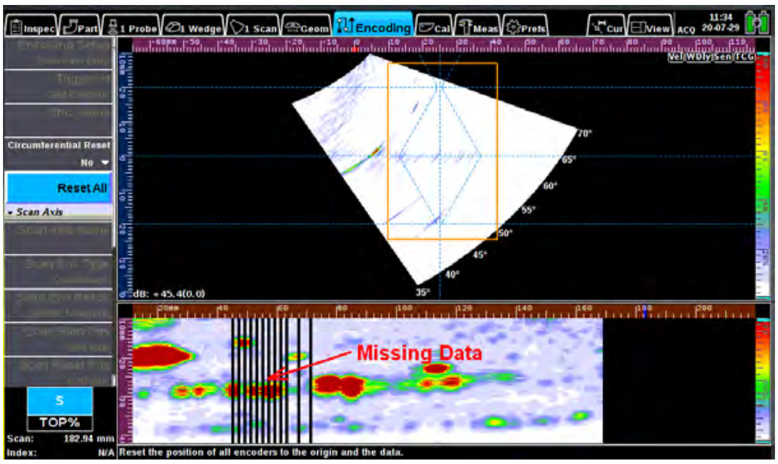


Figure 47: Missing data due to fast or erratic probe movement

- Collect a test scan over a suitable area of the weld. It may be helpful to increase the gain, to confirm that weld beads and any other geometric features appear where expected.

- If everything is satisfactory collect the scans and analyse as required.

Reporting

Once an inspection has been performed most applications require a report to be issued. Usually this will be in a format agreed between the inspector and client, and will contain the following items:

- Details of the customer, part ID, location etc.
- The date and time of inspection.
- Details of the equipment used – instruments, probes, scanners etc., along with serial numbers and calibration status.
- A listing of any defects found (or confirmation that none were found). As a minimum, this should include location, size/severity, and type of defect where possible.
- Where appropriate, images of the part and one or more ultrasonic images of the part and or defects.

The Sonatest mono-element flaw detectors do not attempt to produce full reports but do provide the ability to store and recall screen images for use in reporting. Several examples are shown earlier in this report.

With the Sonatest phased array products (Prisma, veo, veo+) and the attendant UTstudio software, there are a number of options:

1. The instrument itself can produce a PDF report based on the current display and selected parameters.
2. The UTstudio+ software can produce a PDF report based on the current display (which is highly configurable), plus selected parameters and an annotation table.
3. Individual 'windows' can be extracted from UTstudio via drag and drop into a suitable word processor document.

Examples of this are shown in Appendix B.

Appendix A:
Partial list of ultrasonic standards applicable for weld inspection

All revisions noted are current as of 2020, most of these standards are revised or reconfirmed periodically

	BS, EN, BS EN and BS ISO (For EN and ISO standards, other national/ translated implementations should be identical)
General provisions	ISO 10375:1997 Non-destructive testing – Ultrasonic inspection – Characterisation of search unit and sound field
	BS EN ISO 16810:2014 Non-destructive testing – Ultrasonic testing – General principles
Training	BS EN ISO 9712:2012 " Non-destructive testing. Qualification and certification of NDT personnel
Equipment and tools	BS EN ISO 2400:2012 Non-destructive testing – Ultrasonic testing – Specification for calibration block No 1
	BS EN ISO 7963:2010 Non-destructive testing – Ultrasonic testing – Specification for calibration block No 2
	BS EN 12668-1:2010 Non-destructive testing – Characterisation and verification of ultrasonic examination equipment – Part 1: Instruments
	BS EN 12668-2:2010 Non-destructive testing – Characterisation and verification of ultrasonic examination equipment – Part 2: Probes
	BS EN 12668-3:2013 Non-destructive testing – Characterisation and verification of ultrasonic examination equipment – Part 3: Combined equipment
	ISO 12710:2002 Non-destructive testing – Ultrasonic inspection – Evaluating electronic characteristics of ultrasonic test instruments
	ISO 12715:2014 Non-destructive testing – Ultrasonic testing – Reference blocks and test procedures for the characterisation of contact probe sound beams
	ISO 18175:2004 Non-destructive testing – Evaluating performance characteristics of ultrasonic pulse-echo testing systems without the use of electronic measurement instruments
	BS EN ISO 18563-1:2015 Non-destructive testing – Characterisation and verification of ultrasonic phased array equipment – Part 1: Instruments
	BS EN ISO 18563-2:2017 Non-destructive testing – Characterisation and verification of ultrasonic phased array equipment – Part 2: Probes
	BS EN ISO 18563-3:2015 Non-destructive testing – Characterisation and verification of ultrasonic phased array equipment – Part 3: Combined systems
	BS ISO 19675:2017 Non-destructive testing – Ultrasonic testing – Specification for a calibration block for phased array (PAUT)
Techniques	BS EN ISO 15626:2018 Non-destructive testing of welds – Time-of-flight diffraction technique (TOFD) – Acceptance levels
	BS EN ISO 16811:2014 Non-destructive testing – Ultrasonic testing – Sensitivity and range setting
	BS EN ISO 16826:2014 Non-destructive testing – Ultrasonic testing – Examination for discontinuities perpendicular to the surface
	BS EN ISO 16827:2014 Non-destructive testing – Ultrasonic testing – Characterisation and sizing of discontinuities

Special techniques	BS EN ISO 16828:2014 Non-destructive testing – Ultrasonic testing – Time-of-flight diffraction technique as a method for detection and sizing of discontinuities
	BS EN ISO 10863:2011 Non-destructive testing of welds – Ultrasonic testing – Use of time-of-flight diffraction technique (TOFD)
	BS EN ISO 15626:2013 Non-destructive testing of welds – Time-of-flight diffraction technique (TOFD) – Acceptance levels
	BS EN ISO 13588:2019 Non-destructive testing of welds – Ultrasonic testing – Use of automated phased array technology
Welds (w)	BS EN ISO 17640:2018 Non-destructive testing of welds – Ultrasonic testing – Techniques, testing levels and assessment
	BS EN ISO 22825:2017 Non-destructive testing of welds – Ultrasonic testing – Testing of welds in austenitic steels and nickel-based alloys
	BS EN ISO 23279:2017 Non-destructive testing of welds – Ultrasonic testing – Characterisation of indications in welds
	BS EN ISO 11666:2018 Non-destructive testing of welds – Ultrasonic testing – Acceptance levels
	ISO 19285:2017 Non-destructive testing of welds - Phased array ultrasonic testing (PAUT) - Acceptance levels
Tubes and pipes (t)	BS EN ISO 10893-8:2011 Non-destructive testing of steel tubes – Part 8: Automated ultrasonic testing of seamless and welded steel tubes for the detection of laminar imperfections
	BS EN ISO 10893-9:2011 Non-destructive testing of steel tubes – Part 9: Automated ultrasonic testing for the detection of laminar imperfections in strip/plate used for the manufacture of welded steel tubes
	BS EN ISO 10893-10:2011 Non-destructive testing of steel tubes – Part 10: Automated full peripheral ultrasonic testing of seamless and welded (except submerged arc-welded) steel tubes for the detection of longitudinal and/or transverse imperfections
	BS EN ISO 10893-11:2011 Non-destructive testing of steel tubes – Part 11: Automated ultrasonic testing of the weld seam of welded steel tubes for the detection of longitudinal and/or transverse imperfections
	BS EN ISO 10893-12:2011 Non-destructive testing of steel tubes – Part 12: Automated full peripheral ultrasonic thickness testing of seamless and welded (except submerged arc-welded) steel tubes
	BS ISO 10332:2010 Non-destructive testing of steel tubes – Automated ultrasonic testing of seamless and welded (except submerged arc-welded) steel tubes for verification of hydraulic leak-tightness
Terminology	BS EN ISO 5577:2017 Non-destructive testing – Ultrasonic testing – Vocabulary
	BS EN 16018:2011 Non-destructive testing – Terminology – Terms used in ultrasonic testing with phased arrays

Main US Standards
ASTM E114-15 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method
ASTM E164-19 Standard Practice for Contact Ultrasonic Testing of Weldments
ASTM E 317-16, Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse- Echo Examination Instruments and Systems Without the Use of Electronic Measurement Instruments

ASTM E 494-15, Standard Practice for Measuring Ultrasonic Velocity in Materials.
ASTM E 543-15 Specification for Agencies Performing Nondestructive Testing
ASTM E 587-15(2020) , Standard Practice for Ultrasonic Angle-Beam Examination by the Contact Method.
ASTM E1316-20 Standard Terminology for Nondestructive Examinations
ASTM E1324-16 Guide for Measuring Some Electronic Characteristics of Ultrasonic Testing Instruments
ASTM E 1961-16 , Standard Practice for Mechanized Ultrasonic Examination of Girth Welds Using Zonal Discrimination with Focused Search Units.
ASTM E2373 / E2373M-19 Standard Practice for Use of the Ultrasonic Time of Flight Diffraction (TOFD) Technique
ASTM E2700-20 Standard Practice for Contact Ultrasonic Testing of Welds Using Phased Arrays
ASME Boiler and Pressure Vessel Code, Section V , 2019 – Nondestructive Examination
AWS D1.1: Structural Welding Code - Steel
API 1104: Welding of Pipelines and Related Facilities

Appendix B: Veo+ reporting

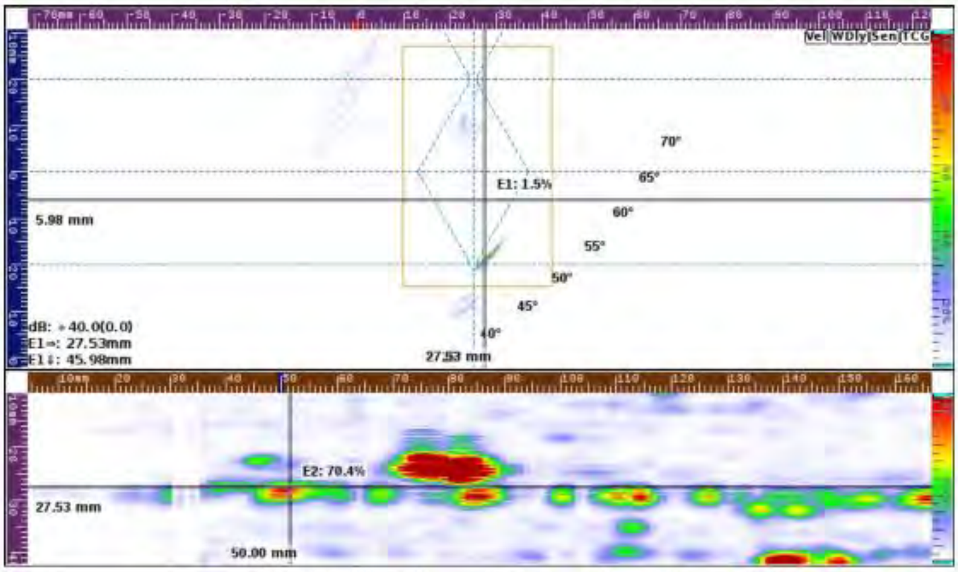
Direct pdf report from veo+

Veo+ Inspection Report

Software: blueorigin, Unit serial #: I016353

Component	Config File Name	File Vers.	Data File Vers.	Operator	Procedure Ref	Inspection Date
	single v weld _0004.urtdata	11	1			2020-07-27 14:48:38

S1 - Sectorial PE Gain	N/A	N/A	N/A	N/A	N/A
40.0 dB					



Legend :

Abbrev.	Description
BPL	Path Length
D	Depth
SD	Surface Dist.
A	Amplitude
L	Length
DLT	Delta

*[Smoothing, Sub-Sampling]

Inspection	Info
Voltage Ar.	50 V
Probe 1 [Freq, Model]	5.00 MHz, X3A-5M64E-0.6x10
Wedge 1 [Velo, Model]	2.337 mm/µs, X3AW-N55S

Encoder Info	
Encoding Setup	Scan Axis Only
Enc. Name	N/A
Scan Enc Resol.	16.0000 ticks/mm

Part	Info
Material	Steel
Velocity [LW/SW]	5.890 mm/µs, 3.240 mm/µs
Part Geometry	Plate
Thickness	20.00 mm
Weld	Single V

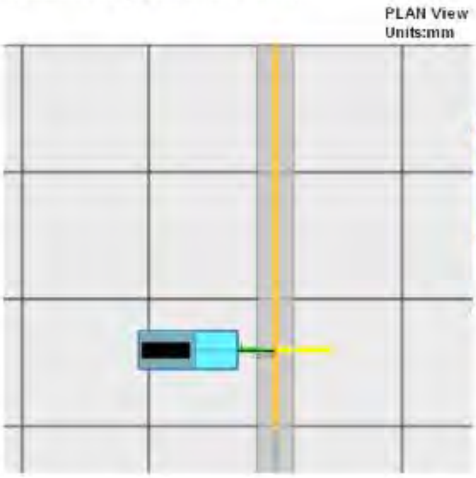
Scan / Cursor	Value1	Value2	Value3	Value4
S1 S-Scan/E1	BPL 73.42 mm	D 45.98 mm	SD 27.53 mm	51.50°
S1 S-Scan/CH1	BPL 0.00 mm	D 80.68 mm	SD -52.32 mm	0.00°
S1 Top View/E2	---	---	SD 27.53 mm	S.Axis 50.00 mm
S1 Top View/CH2	---	---	SD 9.77 mm	S.Axis 6.64 mm

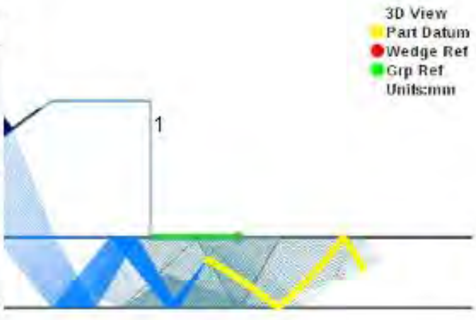
Scan S1 - Sectorial PE	Value
Signal Processing*	High, Auto: 1:4
Filters	Auto: wide high
Software Gain	0.0 dB
Gain , Ref	40.0 dB, 0.0 dB
Focal [Type, Dist]	Constant Path, 90.00 mm
Start/Stop Path	30.00 mm, 95.00 mm
Start/Stop Angle	35.00°, 70.00°
Acq. Freq.	125 MHz

single v weld _0004_0001.pdf Page 1

Veo+ Inspection Report

Software: blueorigin, Unit serial #: I016353





Inspection					
Probe Qty	1	Encoded Axis Ref.	Wedge Reference	Qualification	N/A
Scan Qty	1	Job/Customer	N/A	Procedure Ref	N/A
Voltage Ar.	50 V	Site	N/A	Couplant	N/A
Alarms	Off	Operator	N/A		

Part					
Material	Steel	Velocity LW	5.890 mm/µs	Weld Root Gap	2.00 mm
Condition	N/A	Velocity SW	3.240 mm/µs	Weld Top Bevel Width	24.00 mm
Temperature	0.0°C	Cal. Block Serial #	N/A	Weld Face Left	0.95 mm
Component	N/A	Cal. Block Type	N/A	Weld Top Left Width	12.00 mm
Serial #	N/A	Cal. Block Sensibility Ref.	N/A	Weld Top Left Angle	30.00°
Location Ref	N/A	Rejection Criteria	N/A	Weld Top Left Height	19.05 mm
Part Geometry	Plate	Velocity SW	3.240 mm/µs		
Thickness	20.00 mm	Weld	Single V		

Probe P1 - Array 1D					
Probe Type	Array 1D	Elmt Size Dim 1	0.50 mm	Elmt Pitch Dim 1	0.60 mm
Manufacturer	Sonatest	Pulse Type	Square-Wave	Elmt Offset Dim 1	3.35 mm
Model #	X3A-5M64E-0.6x10	Pulse Width	100.00 ns	Elmt Offset Dim 2	6.50 mm
Serial #	N/A	First Elmt Pin #	1	Element Layout	Bottom Left Row
Frequency	5.00 MHz	Nb Elmt Dim 1	64	Elmt Size Dim 2	10.00 mm

Wedge P1 - Array 1D					
Type	Angular	Back Height	11.70 mm	Roof Angle	0.00°
Manufacturer	Sonatest	Cut Angle	36.00°	Probe Back Dist	0.00 mm
Model #	X3AW-N55S	Front Height	38.60 mm	Probe Side Dist	1.00 mm
Serial #	N/A	Width	25.00 mm	Probe Inset	0.00 mm
Contact Surface	Planar	Length	65.00 mm	Wedge Velocity LW	2.337 mm/µs

single v weld _0004_0001.pdf

Page 2

Veo+ Inspection Report

Software: blueorigin, Unit serial #: I016353

Scan S1 - Sectorial PE					
Type	Sectorial PE	Focal Mode	Constant Path	nbElementsUsedTx	32
Gain , Ref	40.0 dB, 0.0 dB	Focal Dist	90.00 mm	First Elmt RX	17
Software Gain	0.0 dB	Signal Rectification	Full	Last Elmt RX	48
Resolution	0.50°	Filters	Auto: wide high	Beam Qty.	71
Start Angle	35.00°	Sub-Sampling	Auto: 1:4	Sample Qty.	1256
Stop Angle	70.00°	Rejection	Disabled	Path Res.	19.3 spl/mm
Start Path	30.00 mm	Smoothing	High	Acq. Freq.	125 MHz
Range Path	65.00 mm	Contouring	No	Velocity Cal Status	None
Stop Path	95.00 mm	Probe TX/RX	P1 - Array 1D	Wedge Delay Cal Status	None
Zero	0.00 µs	Probe RX	P1 - Array 1D	Sensitivity Cal Status	None
Wave Mode	SW 3.240 mm/µs	First Elmt TX	17	Amp Tolerance	5.00%
Travel Mode	Half Path	Last Elmt TX	48		

Geometry					
W1 Index Off.	-25.00 mm	W1 Rotation	90.0°	Encoder Area CL Offset	0.00 mm
W1 Scan Off.	0.00 mm	Encoder Area CL Pos	0.00 mm	Encoder Area Rotation	0.00°

Encoder parameters					
Encoding Setup	Scan Axis Only	Scan Enc Resol.	16.0000 ticks/mm	Scan Step	1.00 mm
Enc. Name	N/A	Scan Start Pos	0.00 mm	Scan Invert Dir	Yes
Scan Axis Name	N/A	Scan Distance	250.00 mm	Data File Size	43.03 MB
Scan Enc Type	Quadrature	Scan Stop Pos	250.00 mm	Max Phys. Enc. Speed	70.4 mm/s

S1 S-Scan	BPL	Depth	SD	Angle	Beam	Peak	Delta
BX1[Top, Left]	—	12.94 mm	9.77 mm	—	—	—	—
BX1[Bot, Right]	—	64.60 mm	42.01 mm	—	—	—	—
Cartesian Extractor 1 (E1)	73.42 mm	45.98 mm	27.53 mm	—	—	1.5%	—

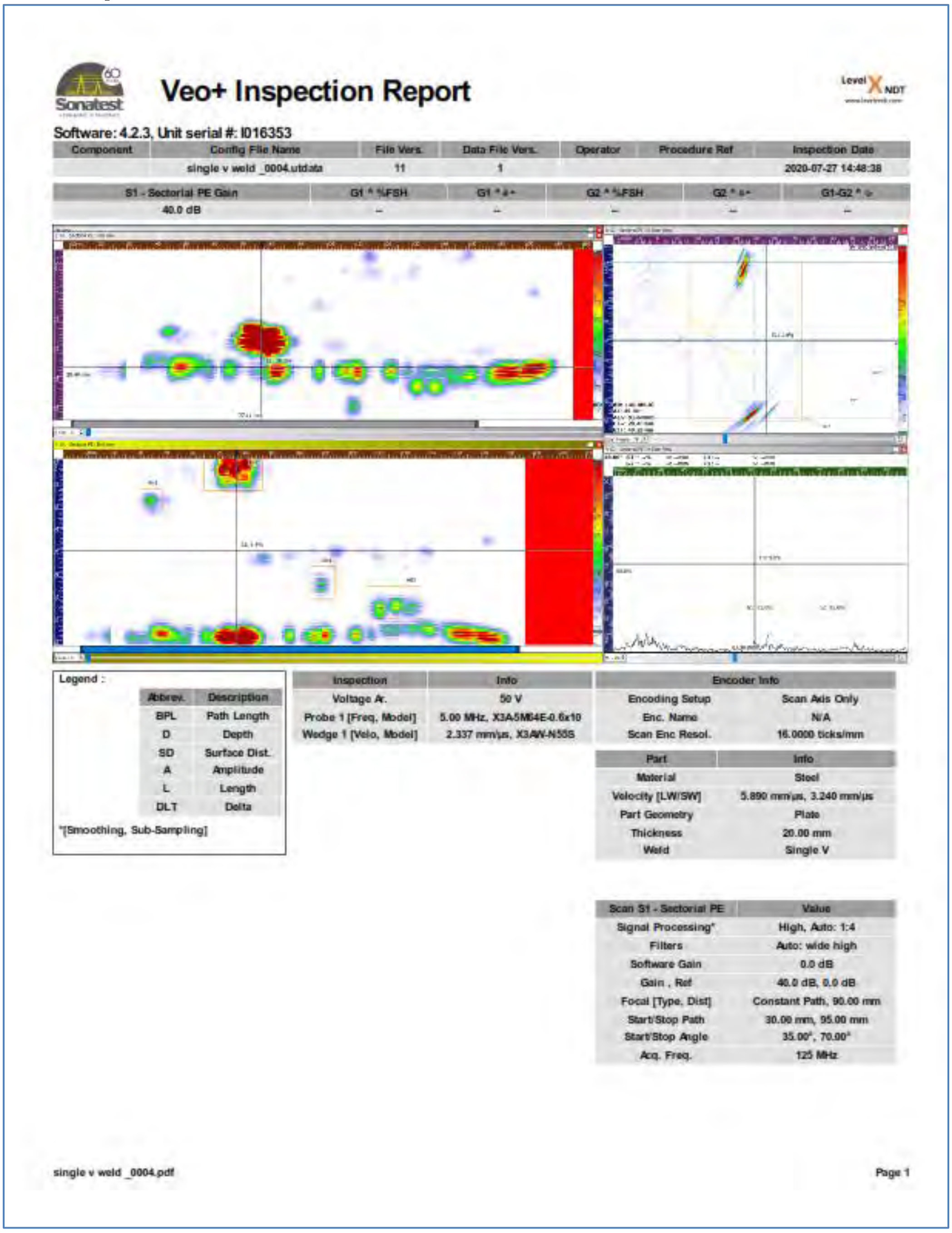
S1 Top View	SD	Scan Axis	Amplitude
Cartesian Extractor 2 (E2)	27.53 mm	50.00 mm	70.4%

Warning Messages	Value
Scan S1 - Sectorial PE	PRF above 1624 Hz may cause phantom echoes.

single v weld _0004_0001.pdf

Page 3 (End)

PDF report from UTstudio+



Veo+ Inspection Report

Software: 4.2.3, Unit serial #: I016353

Component	Config File Name	File Vers.	Data File Vers.	Operator	Procedure Ref	Inspection Date
	single v weld _0004.utdata	11	1			2020-07-27 14:48:38

S1 - Sectorial PE Gain	G1 ^ %FSH	G1 ^ a-	G2 ^ %FSH	G2 ^ a-	G1-G2 ^ a
40.0 dB	--	--	--	--	--

Legend :

Abbrev.	Description
BPL	Path Length
D	Depth
SD	Surface Dist.
A	Amplitude
L	Length
DLT	Delta

*[Smoothing, Sub-Sampling]

Inspection	Info
Voltage Ar.	50 V
Probe 1 [Freq, Model]	5.00 MHz, X3A5M64E-0.6x10
Wedge 1 [Velo, Model]	2.337 mm/µs, X3AW-N55S

Encoder Info	
Encoding Setup	Scan Axis Only
Enc. Name	N/A
Scan Enc Resol.	16.0000 ticks/mm

Part	Info
Material	Steel
Velocity [LW/SW]	5.890 mm/µs, 3.240 mm/µs
Part Geometry	Plate
Thickness	20.00 mm
Weld	Single V

Scan S1 - Sectorial PE	Value
Signal Processing*	High, Auto: 1:4
Filters	Auto: wide high
Software Gain	0.0 dB
Gain , Ref	40.0 dB, 0.0 dB
Focal [Type, Dist]	Constant Path, 90.00 mm
Start/Stop Path	30.00 mm, 95.00 mm
Start/Stop Angle	35.00°, 70.00°
Acq. Freq.	125 MHz

single v weld _0004.pdf

Page 1

Veo+ Inspection Report

Level X NDT

Software: 4.2.3, Unit serial #: I016353

Inspection					
Probe Qty	1	Encoded Axis Ref.	Wedge Reference	Qualification	N/A
Scan Qty	1	Job/Customer	N/A	Procedure Ref	N/A
Voltage Ar.	50 V	Site	N/A	Couplant	N/A
Alarms	Off	Operator	N/A		

Part					
Material	Steel	Velocity LW	5.890 mm/µs	Weld Root Gap	2.00 mm
Condition	N/A	Velocity SW	3.240 mm/µs	Weld Top Bevel Width	24.00 mm
Temperature	0.0°C	Cal. Block Serial #	N/A	Weld Face Left	0.95 mm
Component	N/A	Cal. Block Type	N/A	Weld Top Left Width	12.00 mm
Serial #	N/A	Cal. Block Sensibility Ref.	N/A	Weld Top Left Angle	30.00°
Location Ref	N/A	Rejection Criteria	N/A	Weld Top Left Height	19.05 mm
Part Geometry	Plate	Velocity SW	3.240 mm/µs		
Thickness	20.00 mm	Weld	Single V		

Geometry					
W1 Index Off.	-25.00 mm	W1 Rotation	90.0°	Encoder Area CL Offset	0.00 mm
W1 Scan Off.	0.00 mm	Encoder Area CL Pos	0.00 mm	Encoder Area Rotation	0.00°

	General		Cursor Position				Cursor Meas...	Defect Measurements		General
Name	View	Type	Δ Scan	Center Scan	Center Index	Center True Depth	Max dB REF	Scan 1	Δ Scan	Comment
AN1	3: S1 - Sectorial PE | End View	Box	8.22 mm	44.82 mm	--	11.03 mm• 2	-43.9 dB	41.73 mm	6.17mm	Porosity
AN2	3: S1 - Sectorial PE | End View	Box	21.73 mm	76.23 mm	--	16.58 mm• 2	-34.5 dB	71.29 mm	11.85mm	Root Crack
AN3	3: S1 - Sectorial PE | End View	Box	20.26 mm	137.16 mm	--	11.59 mm• 3	-41.4 dB	129.05 mm	17.22mm	LoF
AN4	3: S1 - Sectorial PE | End View	Box	10.47 mm	110.02 mm	--	7.28 mm• 3	-44.0 dB	106.88 mm	5.24mm	poss LoF?

single v weld _0004.pdf

Page 2 (End)

Veo+ reporting – relevant images extracted from UTstudio+ into Word

This can be customized in almost any way required. Here, we show the annotation table, the top view and the end view (which separates the suspected defects from the root noise more clearly); then, for each indication, we show a sector scan and the A-scan of the relevant indication.

#Data export from file	single v weld _0004.utdata				
#Application name	UTstudio+				
#Application version	4.2.3				
#Unit serial	I016353				
#UTDataFile		1.1			
#CSV File Version		1.3			
#Annotation Table :					
Name	Center True Depth	Max dB REF	Scan 1	Delta Scan	Comment
AN1	11.03 mm	-43.9 dB	41.73 mm	6.17mm	Porosity
AN2	16.58 mm	-34.5 dB	71.29 mm	11.85mm	Root Crack
AN3	11.59 mm	-41.4 dB	129.05 mm	17.22mm	LoF
AN4	7.28 mm	-44.0 dB	106.88 mm	5.24mm	poss LoF?

Figure 48: Formatted annotation table via Excel– this is saved as a .CSV file

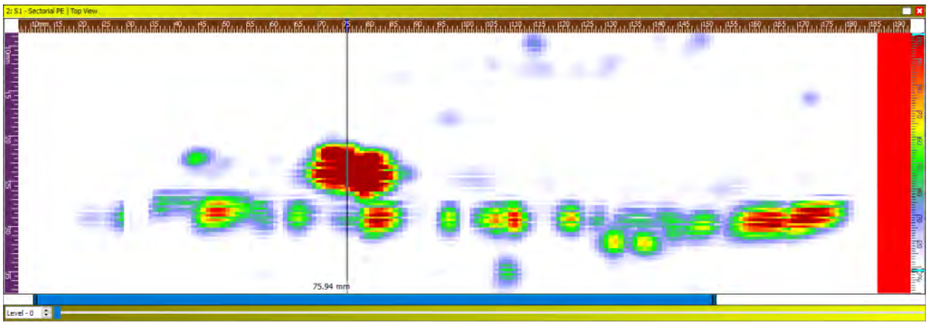


Figure 49: Top view of scanned weld

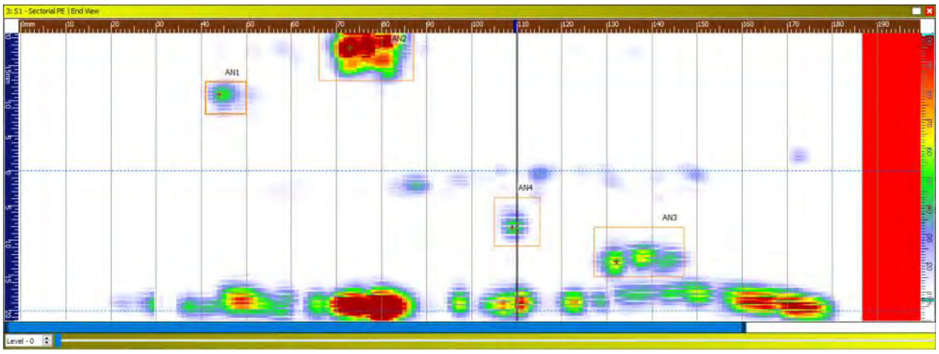
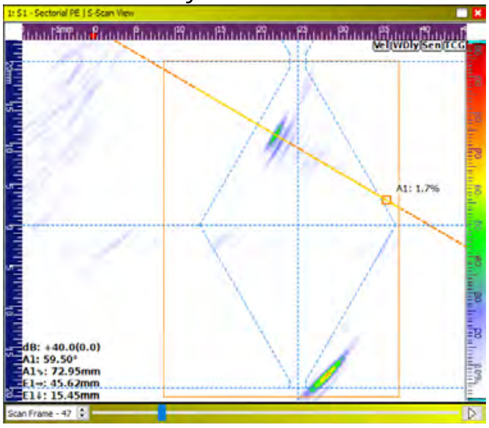


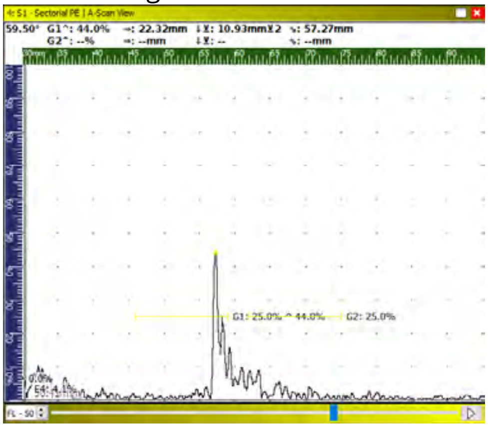
Figure 50: End view of scanned weld. Note that this view shows two 'skips' the weld root is shown at both top and bottom of the image, the weld crown is in the centre (reference line)

Individual defect sector scans and A-scans of defect

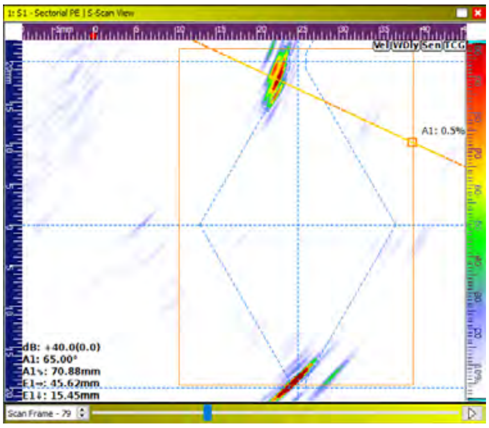
AN01 – Porosity in centre of weld

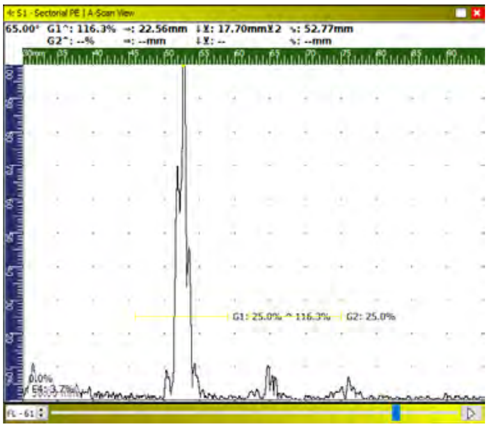


A-scan along extractor line

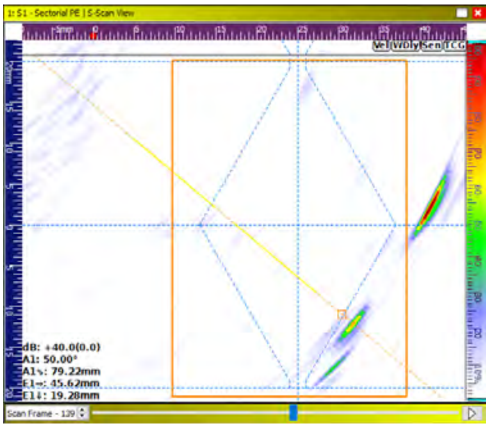


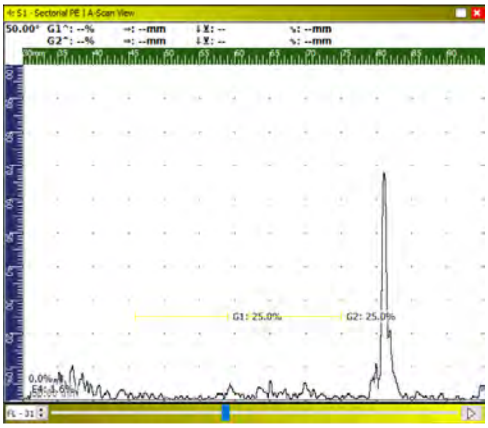
AN02 – Root crack - note that this is 'earlier' than the weld root 'noise'



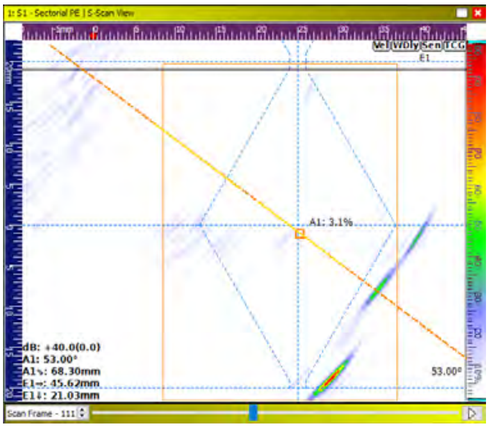


AN03 - Lack of side wall fusion.





AN04 – Suspected LoF



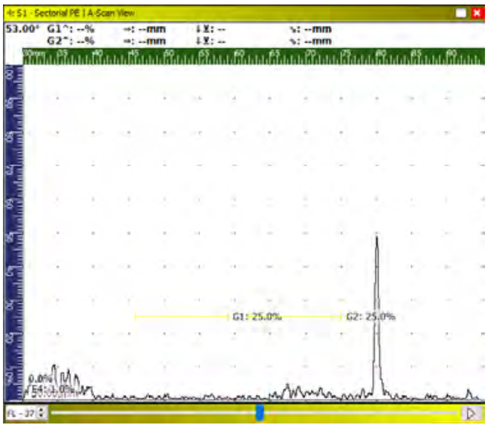


Figure 51: Sector and A-scans for individual indications

Note that these example scan images show indications only from one side; a complete report would, as well as the required inspection information, also show scans from the other side, ideally recorded simultaneously with a second probe in a suitable scanner arrangement.

Ultrasonic Inspection of Welds in Tubes & Pipes

Pipe technology - types of pipe

Steel pipe can be manufactured using a variety of processes. All of these have different trade-offs in terms of feasibility, cost, and quality.

Seamless

The highest quality pipe is made using a seamless process which avoids the weaknesses associated with an unnecessary weld. Most commonly, a billet is heated and then forced over a mandrel. This is then rolled to the desired diameter. Further processing, such as cold drawing, is then used to produce smaller diameter pipes. Seamless tubing is typically only feasible up to a limited diameter, typically of the order of 20-30 centimetres, depending on the process and the initial billet diameter.

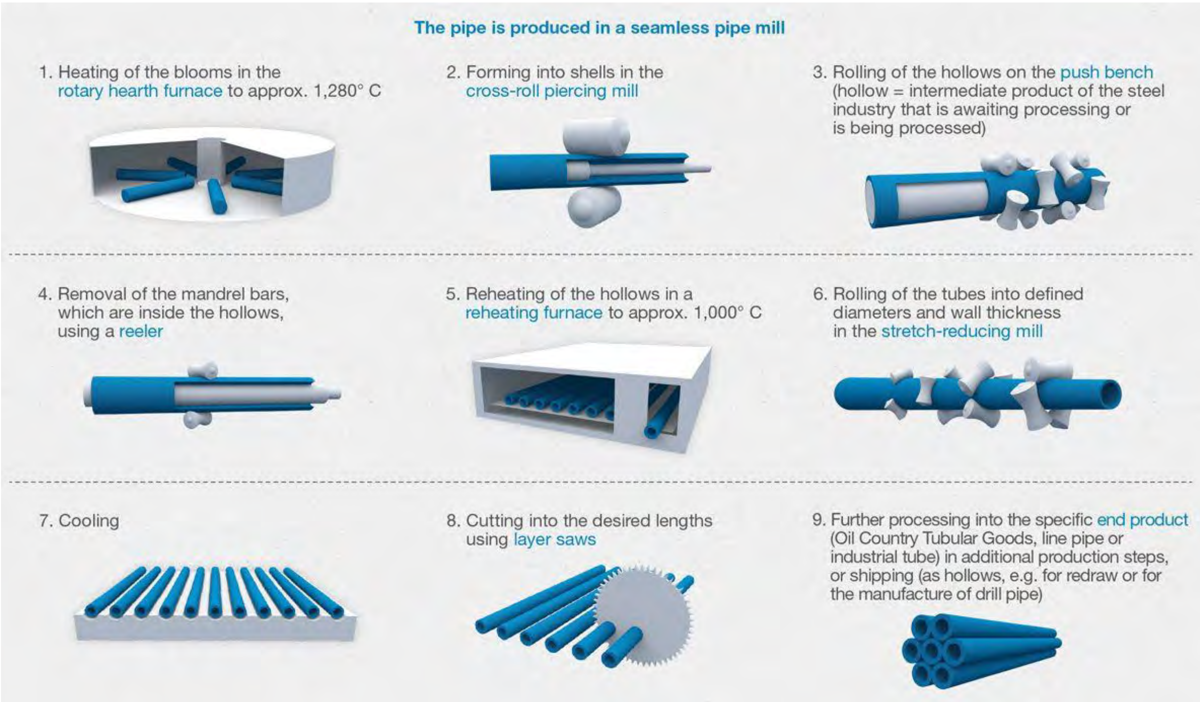


Figure 1 Manufacture of seamless tube (Voestalpine)

Longitudinal seam welded – ERW, SAW

Lower cost tubing is typically made by forming a steel strip into a U-shape, and then further into a circle; this can then be welded using a variety of processes.

Economical mass production of thin-wall steel tubing for many purposes is made using electric resistance welding or high-frequency induction welding. Both are commonly referred to as 'ERW' tubes. The strip edges are forced together and passed through a welding station, where an electric current is applied either directly or via an induction coil which causes a circulating current. This heats the joint, which is then trimmed and rolled to the final size. This can produce relatively high strength tubing, which is typically tested in line using either eddy current or ultrasonic techniques.

For thicker materials, a submerged arc welding (SAW) process is used. This process requires ultrasonic testing.

Spiral welded pipe
Spirally (or helically) welded pipe is manufactured by welding steel strip together at an appropriate angle to give the required diameter. One of the advantages of this process is that the pipes are slightly stronger, because internal pressure stress during use is distributed along the weld rather than pulling it apart. The spiral welding configuration is very suitable for making large diameter steel tubes of relatively thin wall thickness.

It has the particular advantage that steel strip of a fixed width can be used to manufacture a variety of pipe diameters by choosing the appropriate angle – whereas steel strip for longitudinal pipe, once cut, can only be used for a given diameter pipe. This makes spiral welding much more flexible. One disadvantage is that the weld for a given pipe will be longer, and thus the costs associated with welding and inspection will be greater.

Figure 2 Spiral and longitudinally welded pipes.

Pipe sizes
For historical reasons, small diameter pipes are is commonly referred to by their 'nominal size'. The actual size is significantly larger than might be assumed. For example, a 'quarter-inch' pipe is actually 13.7 mm (0.54 inches) in outside diameter, while a 'one inch' pipe is 33.4mm (1.315 inches). The wall thickness of the pipe does not affect the OD. Above 12 inches, sanity prevails, and the 'nominal size' and actual outside diameter are the same. Pipes are commonly referred to by their 'schedule weight'. For full details, refer to the table in Appendix A.

Ultrasonic inspection of pipes

Girth welds

Girth welds, or circumferential welds, are used to join two sections of pipe together or to join sections of pipe to elbows, flanges or other fittings.

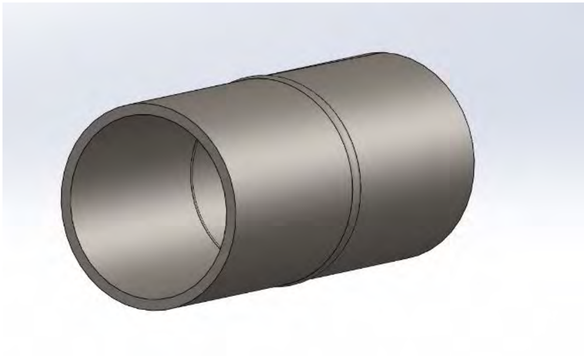


Figure 3 Girth weld

From an ultrasonic perspective, girth welds are very similar to butt welds in in flat plates. When inspection is carried out across the weld, the ultrasonic path is not affected by the curvature of the pipe; however, for small and medium diameter pipes, a shaped wedge (Figure 5) to fit the curvature of the pipe should normally be used. [Tip: The free ESWedgeGap software Figure 8 can be used to confirm an acceptable fit for wedge and pipe diameters.]

Inspection can be done using mono-element, phased array or TOFD methods as discussed in education note E008. The beam can be considered to pass primarily through the centre of the wedge, so calculation will assume the height at the centre.

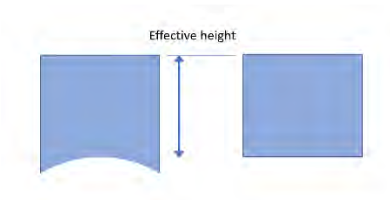


Figure 4 Effective height for shaped wedge

Use of a suitable scanner to keep the probes movement parallel to the weld is pretty much essential. These will be discussed later.

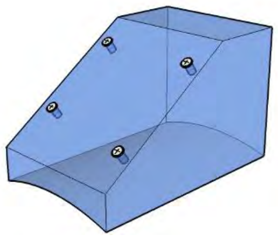


Figure 5 Wedge with axial curvature

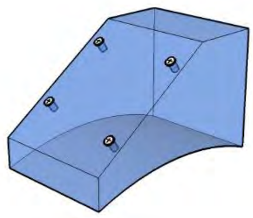


Figure 6 Wedge with circumferential curvature

Figure 7 ROTIX scanner for girth welds (shown without probes for clarity)

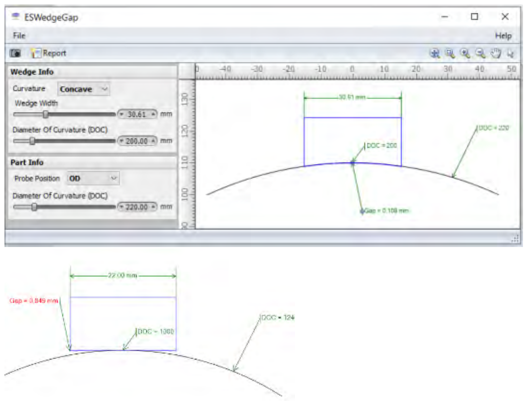


Figure 8 ESWedgeGap software

Longitudinal welds

While in many cases the pipe seam welds will have been tested during manufacture, it is often required to confirm or repeat this at the fabrication stage.

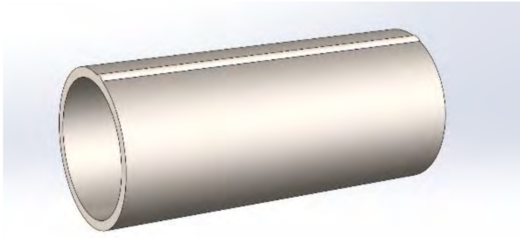


Figure 9 Longitudinal weld

Ultrasonic inspection of longitudinal welds introduces several extra complexities:

1. Other than on the largest diameter tubing, it will be necessary to use a wedge that is shaped to fit the curvature of the pipe (as shown in Figure 6);
2. The incident angle on the weld will vary, depending on the distance between the weld and the probe;
3. For phased array inspection, the focal law calculation is significantly more complex;
4. With TOFD, the shortest path between the two probes is no longer along the surface.

Looking at these in detail:

Wedges

Because the curvature corresponds to the 'long edge', matching the wedge to the pipe diameter is critical.

For example, for an 18-inch pipe the nominal diameter (refer to Appendix A) is 406.4mm.

If we assume a maximum gap of 0.3mm is acceptable, a typical phased array wedge for axial testing is approximately 25mm wide. This would mean that a wedge with a diameter of curvature between flat and around 240mm is acceptable.

On the long axis, an X3 wedge would be around 65mm long. The wedge DOC must be between about 370 and 460mm.

Phased array wedges must be made for the job; there is limited tolerance for using a single wedge on a variety of pipe diameters.

For small mono-element probes it may be possible to use a flat wedge (or to shape the wedge using emery paper or similar), but it is vital to then be able to confirm the probe angle using a suitable test-block, such as a measured piece of pipe with a surface mark. (Ensure this is detected at the correct distance.)

Angles

With a mono-element probe, the Sonatest Wave instrument can show the sound path within a curved pipe. This allows the correct stand-off distances to be determined so that the weld region is scanned fully. If the Wave or similar is not available refer to ISO16811 for guidance.

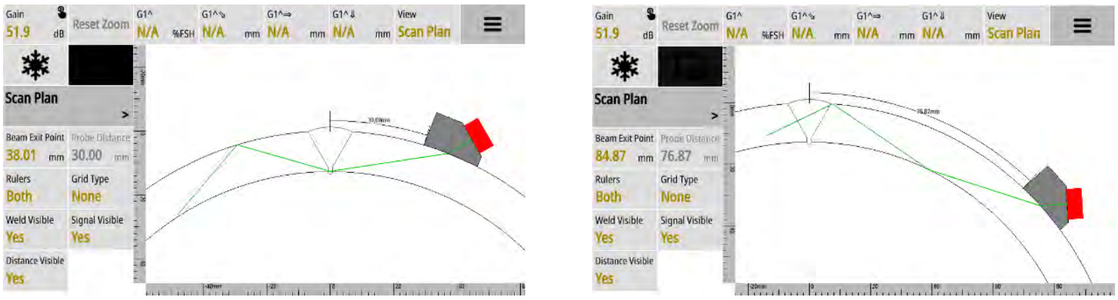


Figure 10 Using the WAVE software to determine scanning distance on seam welds

The Wave can also show when a particular inspection is not possible; for example, with a pipe that is thick in relation to its diameter, the sound beam with a standard 60 degree probe will never reach the inside of the weld and a different probe angle must be chosen.

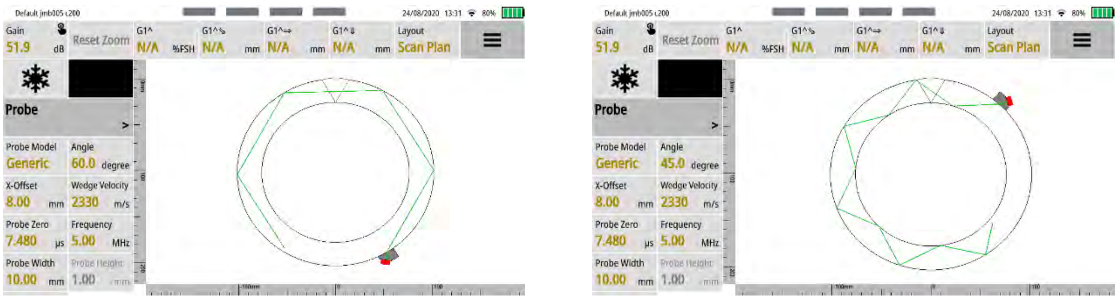


Figure 11 Using the WAVE software to confirm probe angle is suitable, the 60 degree probe does not reach the inner surface of the pipe

Once the sound path within the curved surface is understood, there is minimal difference inspecting girth and seam welds.

Phased array

Inspection of seam welds using phased array complicates the calculation significantly, because we must consider both the irregular shape of the wedge and the changes in angles on reflection.

This can only be done satisfactorily using an instrument or calculation program designed for the job.

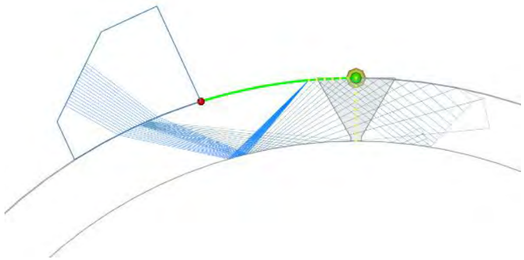


Figure 12 Phased Array beam calculation on a curved surface.

With the veo+, this requires that the curved surface correction software option is installed.

Again, once this is done the inspection is fairly similar to a girth weld of flat inspection.

Time of Flight Diffraction (TOFD)

With TOFD on flat plates, the lateral wave (first arriving, and thus shortest path) is along the surface of the plate. It will often be disrupted by the weld crown.

On curved surfaces the lateral wave will again follow the shortest path, but this is now slightly below the surface. Diffraction from points slightly above and slightly below the line will appear at the same position.

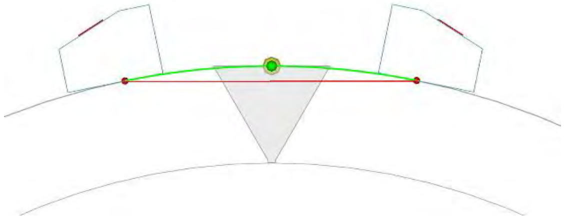


Figure 13 TOFD inspection on a curved surface

This does not mean that TOFD cannot be used across welds on curved surfaces, but considerably more experience and training is required to interpret the results.

Spiral welds

[Sonatest does not currently supply equipment recommended for online inspection of this type.]

Spiral welded tubes should always be inspected as part of the manufacturing process with an automated system, as they are inevitably impossible to manipulate easily for field inspection. Normal practice is to use a fixed inspection setup, with multiple (or phased array) probes located one or two spirals 'downstream' from the welding station. The pipe moves through the system and rotates, so the position of the fixed probes relative to the weld stays constant.

A row of probes is often used to inspect the body of the pipe at the same time.

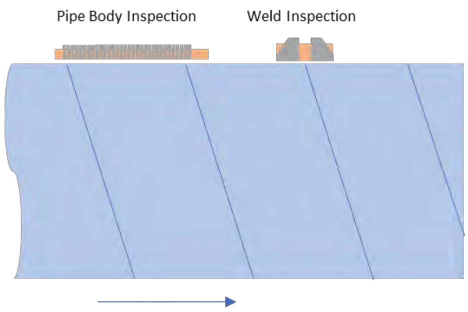


Figure 14 Arrangement for online inspection of Spiral Welded Tube.

If it is necessary to inspect some section of the weld manually, the diameter is normally large enough that the path across the weld line can be treated as nearly flat. However, the skip locations should be confirmed manually.

The author is unaware of any simple scanning systems suitable for manual inspection of spiral welds.

Practical aspects of inspection – scanners

As mentioned above, a key aspect of a successful weld inspection is the selection of a suitable scanner. Scanners perform two vital functions:

- Scanners carry the various probes in a suitable position relative to the weld and allow them to be held accurately while scanning along it. The number of probes is obviously a key aspect of a particular scanner design.
- Scanners also support a suitable encoder, allowing the exact position of the probe or probes to be recorded. This allows accurate measurements of the length and position of a defect to be made from the recorded data.

Broadly we can divide scanners into three categories:

Scanning systems for large diameter pipes

A typical example here would be the Phoenix Magman or the Jireh STIX scanner. These are typically the same as are used for flat welds and might carry a pair of phased array transducers, along with at least one pair of TOFD probes. Alternatively, several conventional probes may be installed.
The critical requirement is that the wheels and tool posts can be adjusted to fit around the pipe in the correct locations.

Figure 15 Jireh STIX scanner

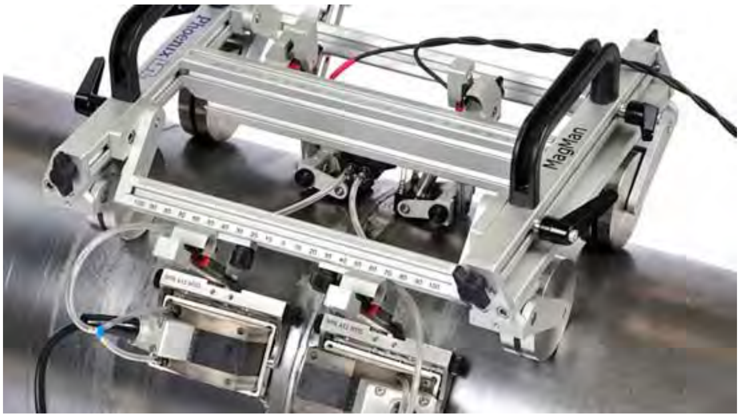


Figure 16 Phoenix Magman

Scanning systems for medium diameter pipes

On medium tubes (i.e a diameter of typically 100 to 300 millimetres), purpose-designed scanners with minimal width are normally required. A typical example would be the Jireh Rotix, or the Phoenix Multimag. These will typically hold a maximum of two pairs of probes.

Figure 17 Jireh ROTIX with Chain assembly

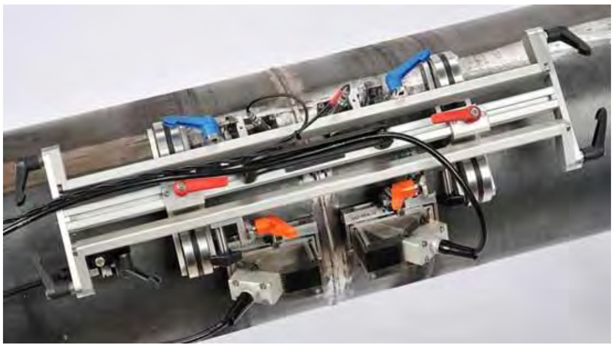


Figure 18 Phoenix Multimag

All these scanner configurations involve compromises, such as width vs. length. Some may be suitable for single sided access (e.g. when testing welds close to flanges or elbows), but this may make them slightly less stable than scanners with wheels on both sides of the weld.

Scanners may be held on to the pipe with magnetic wheels and/or a suitable chain arrangement. For non-magnetic materials, a chain or strap (as shown in Figure 17) is essential.

Scanners for small diameter pipes

For small diameter piping, custom miniature scanners are typically designed to be fixed onto the pipe using a quick release strap, so that they can then be rotated around it with the fingertips. These are typically fitted with one or two specially-designed phased array probes. In many cases the pipes that need to be inspected are close together, so a low-profile design is often important. Typical examples here are the Phoenix Bracelet scanner, the Jireh CIRC-IT, or the Waygate PALM scanner.

Small diameter piping also often has a relatively thin wall, so this may require a specialised technique for the ultrasonic setup. It may for example be difficult to use anything other than high angle scans, which will limit the depth resolution of an indication. Considerable experience can be required to interpret this situation successfully. The recently issued standard ISO 20601-2018 gives useful guidance here.

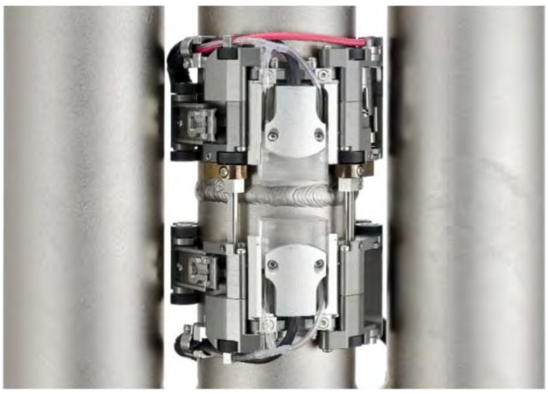


Figure 19 Jireh CIRC-IT

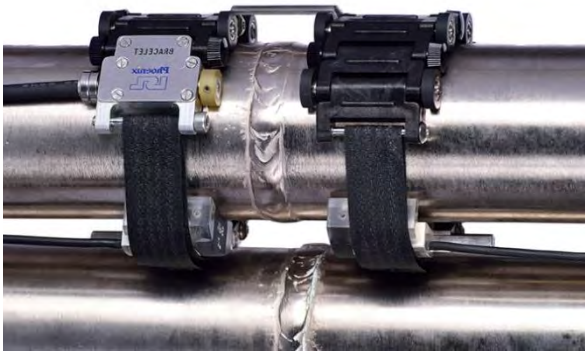


Figure 20 Phoenix Bracelet scanner

In general, all scanners fitted with suitable connectors are compatible with all phased array instruments.

Scanners for longitudinal welds

Normally these will be similar to those used for large diameter piping – and many scanner designs are adaptable for both applications – but it is essential that the wheels and probes can be adjusted to match the curvature in the circumferential direction.

Figure 21 Jireh 'STIX' scanner with 'long seam weld' option

Appendix A Pipe sizes

Actual pipe diameters for twelve inch and below are not the same as the nominal pipe size.

Upper figure is thickness in mm, lower figure is weight in kgm^{-1}

Size NB	O.D. inches *mm*	Pipe Schedules															
		5s	5	10	10s	20	30	40s Std	40	60	80s E.H.	80	100	120	140	160	Dbl. E.H.
1/8	0.405 *10.29*		0.89 *0.21*	1.24 *0.28*	1.24 *0.28*			1.73 *0.36*	1.73 *0.36*		2.41 *0.47*	2.41 *0.47*					
1/4	0.54 *13.72*		1.24 *0.38*	1.65 *0.49*	1.65 *0.49*			2.24 *0.63*	2.24 *0.63*		3.02 *0.80*	3.02 *0.80*					
3/8	0.675 *17.15*		1.24 *0.49*	1.65 *0.63*	1.65 *0.63*			2.31 *0.84*	2.31 *0.84*		3.20 *1.09*	3.20 *1.09*					
1/2	0.84 *21.34*	1.65 *0.80*	1.65 *0.80*	2.11 *1.00*	2.11 *1.00*			2.77 *1.27*	2.77 *1.27*		3.73 *1.62*	3.73 *1.62*				4.78 *1.94*	7.47 *2.55*
3/4	1.05 *26.67*	1.65 *1.02*	1.65 *1.02*	2.11 *1.28*	2.11 *1.28*			2.87 *1.68*	2.87 *1.68*		3.91 *2.19*	3.91 *2.19*				5.56 *2.88*	7.82 *3.63*
1	1.315 *33.40*	1.65 *1.29*	1.65 *1.29*	2.77 *2.09*	2.77 *2.09*			3.38 *2.50*	3.38 *2.50*		4.55 *3.23*	4.55 *3.23*				6.35 *4.23*	9.09 *5.45*
1-1/4	1.66 *42.16*	1.65 *1.65*	1.65 *1.65*	2.77 *2.69*	2.77 *2.69*			3.56 *3.38*	3.56 *3.38*		4.85 *4.46*	4.85 *4.46*				6.35 *5.60*	9.70 *7.76*
1-1/2	1.9 *48.26*	1.65 *1.90*	1.65 *1.90*	2.77 *3.10*	2.77 *3.10*			3.68 *4.04*	3.68 *4.04*		5.08 *5.40*	5.08 *5.40*				7.14 *7.23*	10.16 *9.54*
2	2.375 *60.33*	1.65 *2.39*	1.65 *2.39*	2.77 *3.93*	2.77 *3.93*			3.91 *5.44*	3.91 *5.44*		5.54 *7.47*	5.54 *7.47*				8.74 *11.1*	11.07 *13.4*
2-1/2	2.875 *73.03*	2.11 *3.68*	2.11 *3.68*	3.05 *5.25*	3.05 *5.25*			5.16 *8.62*	5.16 *8.62*		7.01 *11.4*	7.01 *11.4*				9.53 *14.9*	14.02 *20.4*
3	3.5 *88.90*	2.11 *4.51*	2.11 *4.51*	3.05 *6.45*	3.05 *6.45*			5.49 *11.3*	5.49 *11.3*		7.62 *15.3*	7.62 *15.3*				11.13 *21.3*	15.24 *27.7*
3-1/2	4 *101.6*	2.11 *5.17*	2.11 *5.17*	3.05 *7.40*	3.05 *7.40*			5.74 *13.6*	5.74 *13.6*		8.08 *18.6*	8.08 *18.6*					16.15 *34.0*
4	4.5 *114.3*	2.11 *5.83*	2.11 *5.83*	3.05 *8.35*	3.05 *8.35*			6.02 *16.1*	6.02 *16.1*	7.14 *18.8*	8.56 *22.3*	8.56 *22.3*		11.13 *28.3*		13.49 *33.5*	17.12 *41.0*
4-1/2	5 *127.0*							6.27 *18.6*			9.02 *26.2*						18.03 *48.4*
5	5.563 *141.3*	2.77 *9.45*	2.77 *9.45*	3.40 *11.6*	3.40 *11.6*			6.55 *21.8*	6.55 *21.8*		9.53 *30.9*	9.53 *30.9*		12.70 *40.2*		15.88 *49.1*	19.05 *57.4*
6	6.625 *168.3*	2.77 *11.3*	2.77 *11.3*	3.40 *13.8*	3.40 *13.8*			7.11 *28.2*	7.11 *28.2*		10.97 *42.5*	10.97 *42.5*		14.27 *54.2*		18.26 *67.4*	21.95 *79.1*
7	7.625 *193.7*							7.65 *35.1*			12.70 *56.6*						22.23 *93.9*
8	8.625 *219.1*	2.77 *14.8*	2.77 *14.8*	3.76 *19.9*	3.76 *19.9*	6.35 *33.3*	7.04 *36.8*	8.18 *42.5*	8.18 *42.5*	10.31 *53.0*	12.70 *64.6*	12.70 *64.6*	15.09 *75.7*	18.26 *90.7*	20.62 *100.8*	23.01 *111.2*	22.23 *107.8*
9	9.625 *244.5*							8.69 *50.4*			12.70 *72.5*						
10	10.75 *273.1*	3.40 *22.6*	3.40 *22.6*	4.19 *27.8*	4.19 *27.8*	6.35 *41.7*	7.80 *51.0*	9.27 *60.2*	9.27 *60.2*	12.70 *81.5*	12.70 *81.5*	15.09 *95.7*	18.26 *114.5*	21.44 *132.7*	25.40 *154.9*	28.58 *172.1*	25.40 *155.0*
11	11.75 *298.5*							9.53 *67.8*			12.70 *89.4*						
12	12.75 *323.9*	3.96 *31.4*	4.19 *33.0*	4.57 *36.0*	4.57 *36.0*	6.35 *49.7*	8.38 *65.1*	9.53 *73.8*	10.31 *79.7*	14.27 *108.9*	12.70 *97.4*	17.48 *131.7*	21.44 *159.5*	25.40 *186.8*	28.58 *207.9*	33.32 *238.7*	
14	14 *355.6*	3.96 *34.3*		6.35 *54.6*	4.78 *41.3*	7.92 *68.0*	9.53 *81.2*	9.53 *81.2*	11.13 *94.3*	15.09 *126.4*	12.70 *107.3*	19.05 *157.9*	23.83 *194.5*	27.79 *224.3*	31.75 *253.3*	35.71 *281.4*	
16	16 *406.4*	4.19 *41.5*		6.35 *62.6*	4.78 *47.2*	7.92 *77.9*	9.53 *93.1*	9.53 *93.1*	12.70 *123.2*	16.66 *160.0*	12.70 *123.2*	21.44 *203.1*	26.19 *245.3*	30.94 *286.2*	36.50 *332.6*	40.49 *364.8*	
18	18 *457.2*	4.19 *46.8*		6.35 *70.5*	4.78 *53.2*	7.92 *87.8*	11.13 *122.1*	9.53 *105.1*	14.27 *156.0*	19.05 *205.7*	12.70 *139.1*	23.83 *254.2*	29.36 *309.5*	34.93 *363.3*	39.67 *408.1*	45.24 *459.1*	
20	20 *508.0*	4.78 *59.2*		6.35 *78.5*	5.54 *68.9*	9.53 *117.0*	12.70 *154.9*	9.53 *117.0*	15.09 *182.9*	20.62 *247.6*	12.70 *154.9*	26.19 *310.9*	32.54 *381.1*	38.10 *441.1*	44.45 *507.6*	50.01 *564.0*	
24	24 *609.6*	5.54 *82.4*		6.35 *94.4*	6.35 *94.4*	9.53 *140.8*	14.27 *209.5*	9.53 *140.8*	17.48 *254.8*	24.61 *354.3*	12.70 *186.8*	30.96 *441.1*	38.89 *546.8*	46.02 *639.0*	52.37 *718.9*	59.54 *806.4*	
26	26 *660.4*				7.92 *127.4*	12.70 *202.6*		9.53 *152.7*			12.70 *202.6*						
28	28 *711.2*				7.92 *137.3*	12.70 *218.5*	15.88 *271.9*	9.53 *164.7*									
30	30 *762.0*	0.25 *79.4*		7.92 *146.8*	7.92 *147.2*	12.70 *234.4*	15.88 *291.8*	9.53 *176.6*			12.70 *234.4*						
32	32 *812.8*				7.92 *157.1*	12.70 *250.3*	15.88 *311.7*	9.53 *188.5*	17.48 *342.4*		12.70 *250.3*						
34	34 *863.6*				7.92 *167.0*	12.70 *266.2*	15.88 *331.5*	9.53 *200.4*	17.48 *364.3*								
36	36 *914.4*				7.92 *177.0*		15.88 *351.4*	9.53 *212.3*	19.05 *420.2*		12.70 *282.1*						

References

ESWedgegap software can be downloaded from https://eclipsescientific.com/Software/Download/SetupESWedgeGap.exe

Ultrasonic Inspection of Welds in Nozzles, Nodes, Curved Surfaces & TKY Joints

These notes should be read in sequence; this document is supplemental to the first and second, and assumes the reader is familiar with the other documents.

Further notes will discuss other applications using ultrasonic inspection technology.

Nodes, Nozzles, and Joints - Terminology

The general term covers a huge range of possible weld configurations of joints between various plates and pipes. Different approaches must be taken for each, and often it will be the responsibility of the operator to select and optimize an appropriate inspection configuration - so it is important to understand the terminology we are dealing with.

Corner joints are, broadly, any two pieces of plate metal joined at a non-zero angle. T-joints are two pieces joined such that one butts onto the continuous surface of the other.

Cruciform joints are three (possibly four) pieces joined such that the section resembles a cross.

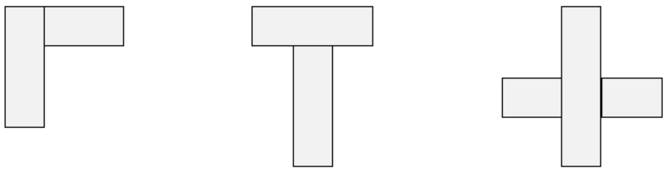


Figure 1 Simple joint shapes

When two (or more) tubular sections are joined together, we describe these joins as **nozzles** where the joining piece is much smaller (typically up to half the diameter) than the main tube, or **nodes** where they are of similar diameter. Nodes may be closed (where the main pipe is not cut, i.e. purely for structural joints) or open to allow fluid flow.

We can describe joints as **set-on** when the joining piece is cut to go outside the main piece or **set-through** when it passes through the piece.

Figure 2 Typical weld preparation (single sided) for set-on and set-through nozzle

A right-angled tubular joint is a T joint; at other angles it is known as a Y joint, and when there is more than one joint at a site as a K joint.as shown in Figure 3.

Nozzles in particular can also be offset from the centre line of the main part, making inspection more complicated. In general, inspection of complex joints requires operators with considerably more experience and additional training compared to simpler welded joints in plates and pipes.

Figure 3 T, K and Y tubular joints.

Corner Joint

The corner joint is very simple to visualize: two pieces of metal come together at right angles. But even with this simple shape, there are many possible configurations of weld. Some typical examples would be as shown in Figure 4.

Typically, the choice of weld configuration will be determined by required characteristics and access, and the choice of inspection approach will be determined by which surfaces can be accessed and by the weld configuration. As always, we want to ensure that the sound beam reaches critical weld geometries at a favourable angle for detection. We must of course also ensure that we inspect for defects within the weld, and for transverse defects.

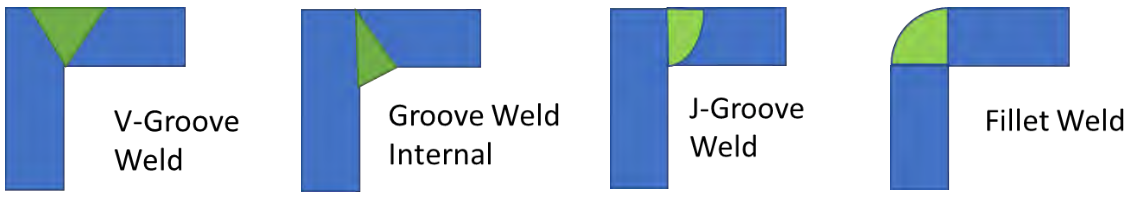


Figure 4 Corner joint: possible weld geometries

As was discussed in the two previous notes, it is desirable to design an inspection such that the sound beam hits the weld preparation at close to 90 degrees. Some thought will show that this is difficult for some of the above configurations. We will discuss each case.

External V-groove weld

The V-groove weld can be inspected easily with suitable choice of preparation angles (a 30-degree shear wave cannot be reliably generated, so 45-degree was chosen for the outside preparation on the outside weld): either from the outside, with the probe in positions B and D, or from the inside, with the probe in positions A and C.

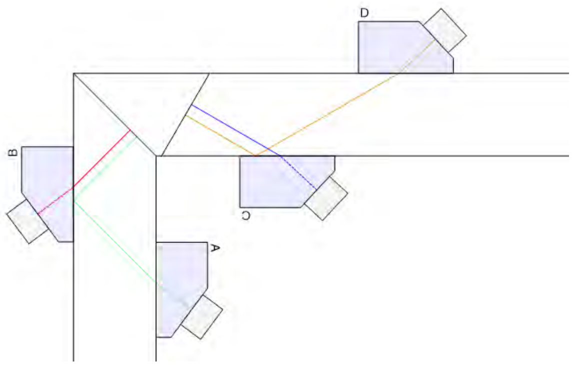


Figure 5 Inspection of V-groove corner weld

Internal groove weld

In the case of the internal weld, only one side of the weld is prepared to an angle. Unless access to the outside is available, any lack of fusion defects on the 90-degree surface may be difficult to find reliably. When the outside can be accessed. any lack of fusion defects can be easily found with a zero-degree probe from the outer surface. It will be necessary to keep precise track of the probe

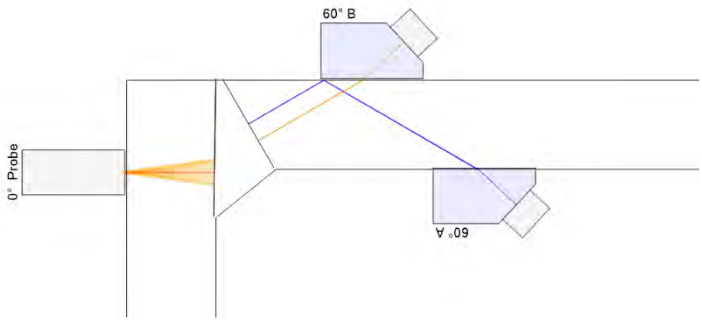


Figure 6 Inspection of corner weld with internal groove.

position, as lack of fusion defects can easily be confused with reflections from the vertical face.

External J-weld

The situation for the external J-weld is similar: again, the 90-degree face can only be easily inspected from the external 'vertical' face.

Because the curved preparation face is not at a constant angle, inspection with a range of sound beam angles is recommended. A phased array sector scan is advantageous here.

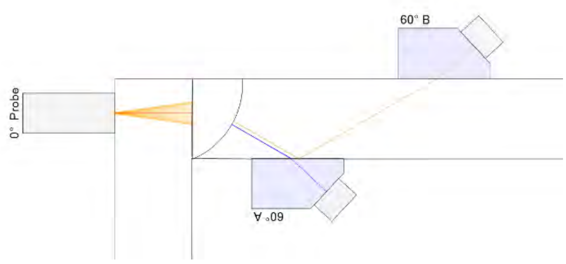


Figure 7 Inspection of J-groove corner weld.

Fillet weld

For the fillet weld, unless the fillet has been ground flat there is no direct sound path that will do this. Fillet welds are generally avoided where the application is considered sufficiently critical to require ultrasonic NDT.

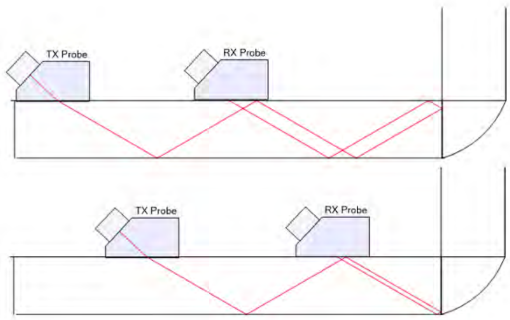


Figure 8 Tandem inspection for perpendicular surface.

However, where inspection of such a weld is deemed essential, we may be able to use a 'tandem' probe arrangement, where one probe transmits and another receives. In practice this is quite complex to arrange easily, since the two probes have to move independently to cover the full height of the weld. It is worth noting that the latest FMC-TFM phased array equipment provides a good solution for this.

Of course, we will also have to use appropriate single probe scans to find other defects within the weld.

T-Joints and 'Cruciform' Joints

These consist of two or three metal plates joined at right angles. The welded joints may be single or double sided.

Figure 9 T and Cruciform joints

Again, the requirement is to develop a scanning plan that, where possible, gives full coverage of all possible defect zones within the weld.

In the case of the 'cruciform' joint, it is not possible to scan the fusion faces of the weld with a normal beam probe because the other piece of metal is in the way. Instead, a very shallow beam probe (e.g. 80-degree) should be used, as shown by Probe C in Figure 11

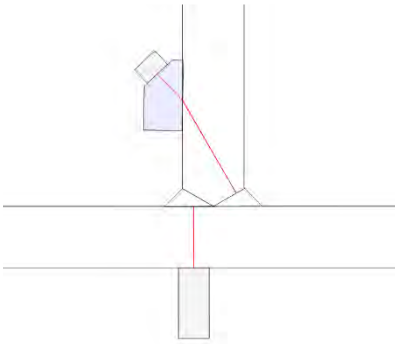


Figure 10 Typical scans for inspection of a T-joint

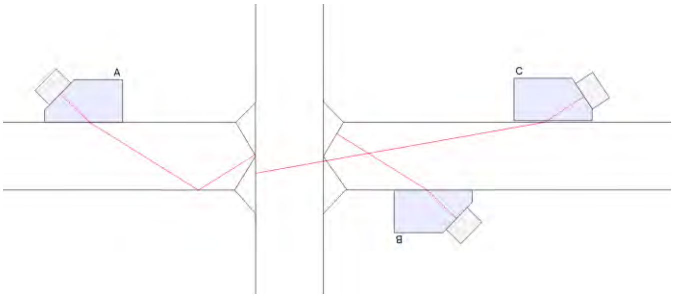


Figure 11 Typical scans for inspection of a cruciform joint

With complex joints of this nature, there are many possible scan directions and angles that can be used. Figure 12 (extracted from BS3923-1:1986) shows possible scanning locations and directions.

The selection of scans used will depend on the size, exact configuration, and service requirements for the joint. In many cases this will be mandated by a customer design specification or an agreed standard.

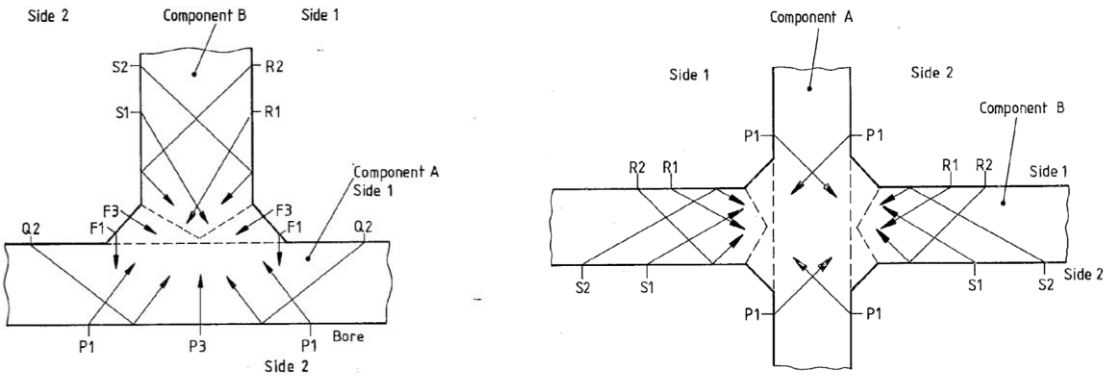


Figure 19. Section through structural T-joint or set-through nozzle weld (double-sided

Figure 20. Section through cruciform joint

Figure 12 Possible angles for inspection of T and cruciform joints from BS3923-1:1986

The Sonatest WAVE instrument allows the user to model the sound reflection pattern inside a limited range of Corner and T-Joint configurations, as shown in Figure 13 and Figure 14.

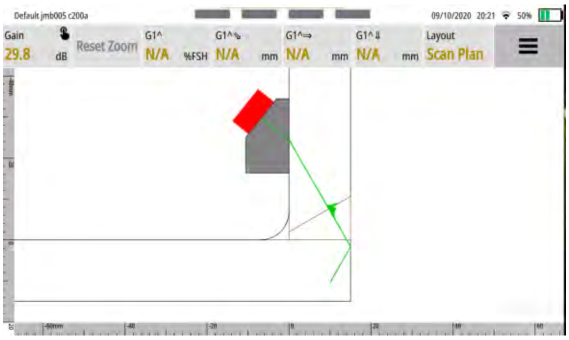


Figure 13 Corner joint on Sonatest WAVE

Figure 14 T-joint on Sonatest WAVE

Scanning with Phased Array Probes

As shown in Figure 15, T and cruciform joints may be scanned with phased array probes, reducing the number of scans required and the need for rastering. Ideally scans from all surfaces should still be carried out: where this is not possible, the extent of any unscanned areas can often be reduced by comparison with mono-element probes, because a wider range of angles is available. Where possible, a suitable scanner should be used.

Again, care is needed in interpreting the results: a few phased array systems allow a complex joint to be modelled, allowing reflections to be fully understood, When this facility is not available an appropriate flat plate representation for each scanning direction can be used with care.

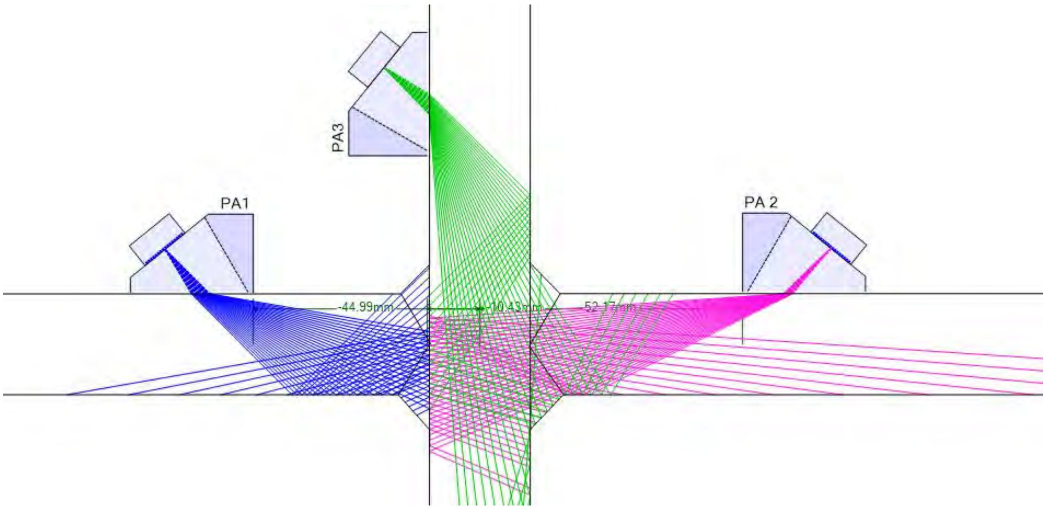


Figure 15 Phased array scans of cruciform joint

Inspection of Tubular Joints

The complexity of ultrasonic inspection of tubular joints results primarily from the changing geometry of the joint as we move along it.

If we take a cross section through a typical arrangement as shown below:

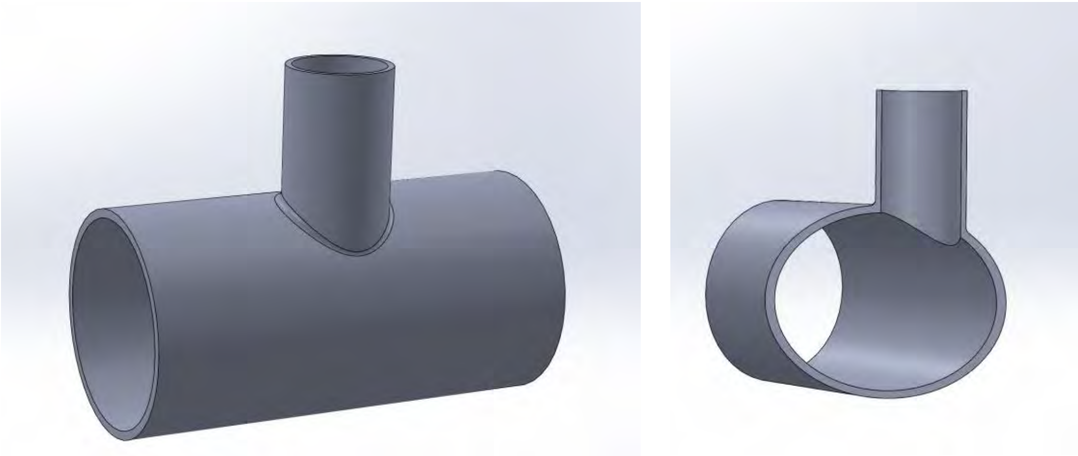


Figure 16 Example Tubular Joint, showing cross section

It is obvious that the geometry on the two sides of the joint is very different – at one side it is close to a right-angle, at the other close to 140 degrees.

The recommended approach is to divide the weld into several zones, as shown in Figure 17. The number of zones selected is a compromise between accuracy and complexity and typically the larger the pipe the more zones will be allocated.

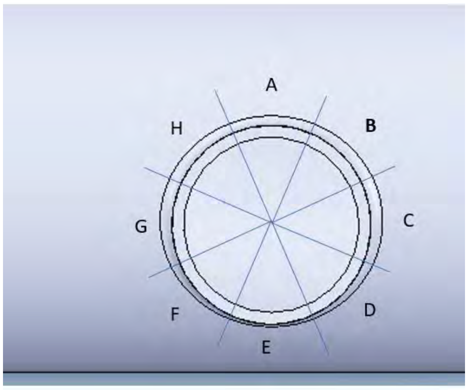


Figure 17 Typical scanning zones for joint

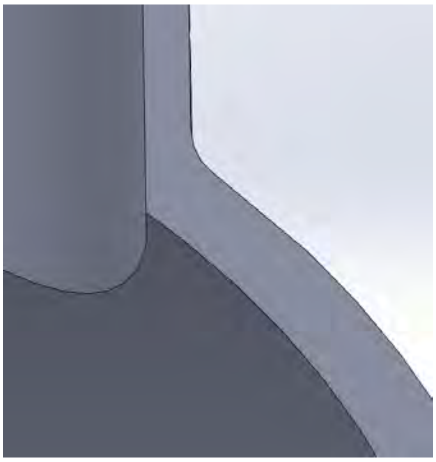


Figure 18 Closeup of 'Zone F' geometry

In this case the pipe exits at 90 degrees, although it is not centred, so zones B & H, C & G, and D & F will have equivalent, although reversed, geometry.

For each zone an appropriate scan plan must be developed, and suitable probe angles and scanning patterns assessed.

Figure 19 shows a scanning approach for zone 'F' (the cross-section shown in Figure 18) It will be noted that some parts of the weld are impossible to insect fully without a probe on the inside of the assembly, and there will be times when this is not feasible.

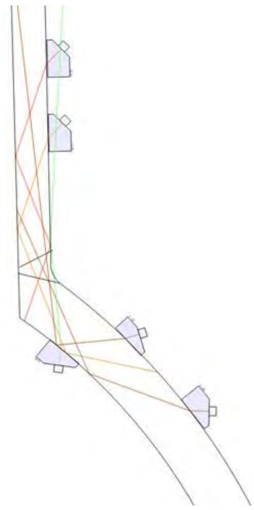


Figure 19 Scan approach for 'Zone F'

Sometimes it is preferable to design the joint with a relatively short 'stub' pipe, allowing access to inspect the joint properly, and then weld on a longer pipe.

In an ideal world, the design of joints will take inspectability into account and ensure that all joints can be fully inspected, whether by ultrasound or some other method. In practice this is not always possible, and the design analysis must consider the possibility of 'undetected defects' and ensure that they are mitigated to the maximum extent possible.

This is a situation where you cannot 'inspect out' problems; in these cases, welder qualification and experience is at least as important as the inspection.

The Sonatest WAVE instrument allows some tubular joint cross sections to be modelled. (Figure 20)

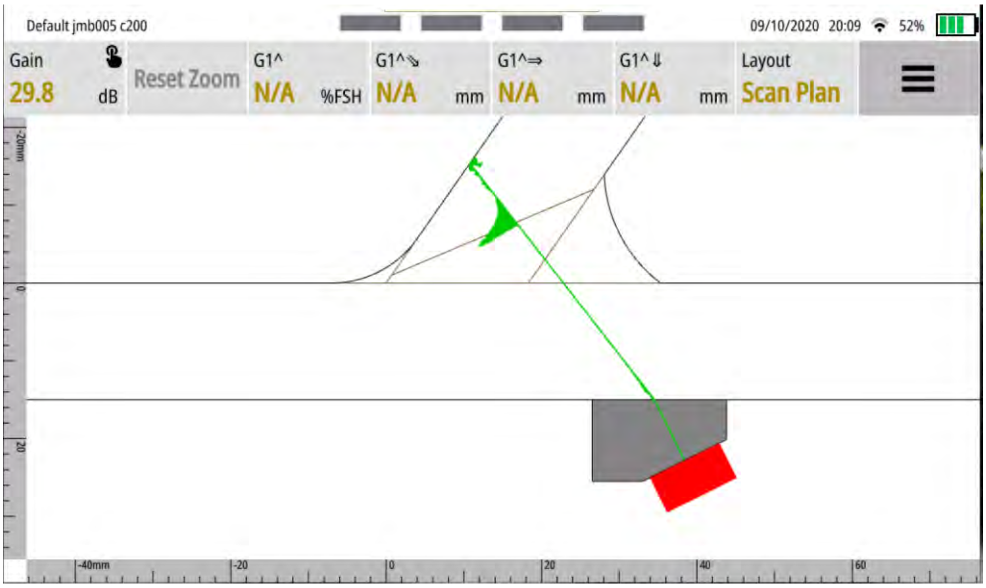


Figure 20 Angled joint simulated on Sonatest WAVE

Tubular Joint Inspection with Phased Array

Techniques for phased array inspection of nozzles are being developed. In concept this is straightforward, but interpretation of defect position can be difficult unless the instrument used is capable of 'understanding' the geometry of the structure.

Scanning from a side with a 'straight' approach to the weld, will give more easily interpreted results as shown in Figure 23, but obviously this is not always possible.

Again, it will be necessary to vary the probe offset to keep a constant distance to the weld.

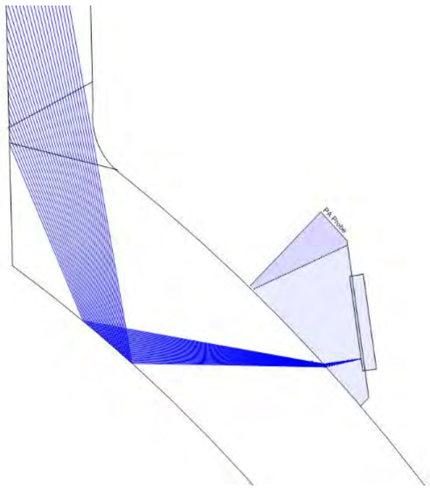


Figure 22 Phased array scan of tubular joint

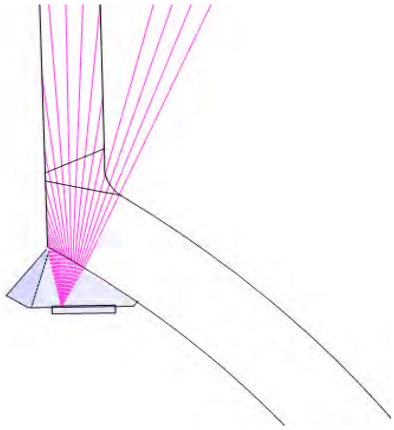


Figure 21 Phased array internal scan

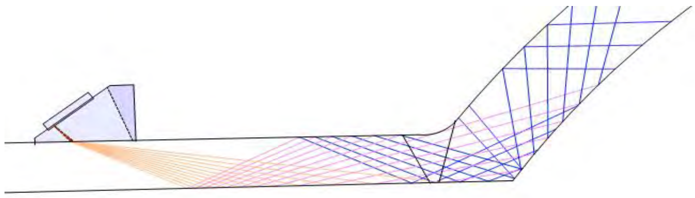


Figure 23 Scan from joining pipe

The scans shown in Figure 22 and Figure 23 will still not give full coverage of the weld zone at an optimal angle, and it may be desirable to access the inside of the assembly as shown in Figure 21

Plotting multiple angles within many tubular joint structures is impractical without specialized software, so ultimately inspection of complex tubular structures is best done using manual mono-element techniques unless phased array equipment with automatic geometry tracking is available.

Some high-end equipment (for example the Zetec TOPAZ system with Ultravision software, shown in Figure 24 allows a CAD model of a joint to be imported; the correct cross section is then selected based on encoder positioning and echoes plotted appropriately. However, it may still be necessary to manually control the offset from the weld.

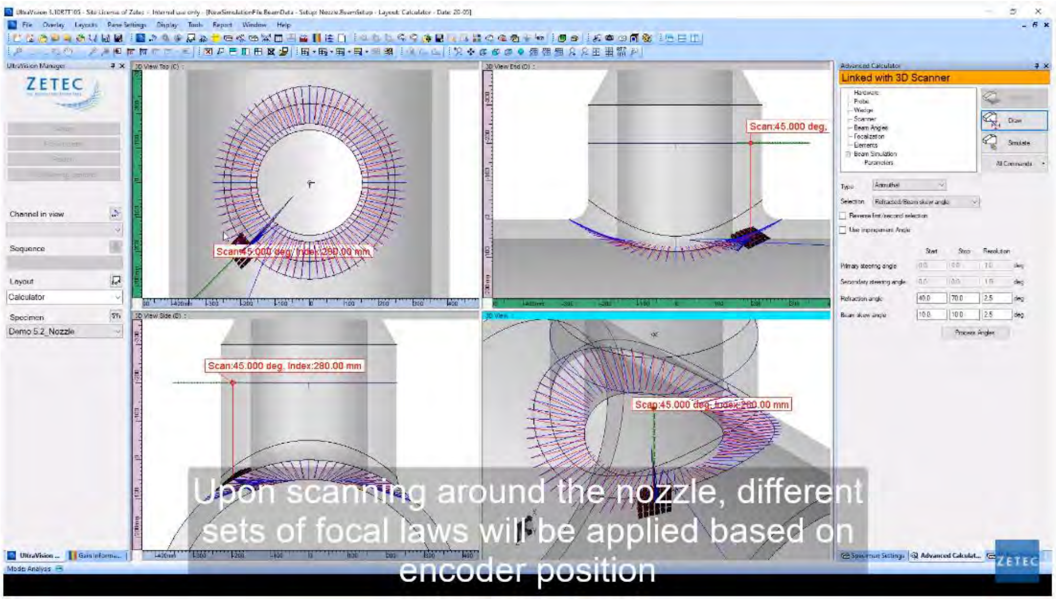


Figure 24 Zetec Ultravision, image from YouTube video.

However, for 'simpler configurations, particularly straight joints where the joining pipe is significantly smaller than the main one (typically greater than around 5x diameter ratio) approximating the configuration to a pipe welded into a flat plate, a standard phased array setup such as the veo+ can be used very effectively. [i]

In applications where the development cost is justified, it seems likely that fully automated scanning systems, possibly robotic, will be developed in future.

Scanners

Scanning systems to enable probe tracking and recording of results from Nozzle scans are available, for example, Phoenix produce the NozzleScan, and a version of the Jireh Rotix configured for nozzle inspection is available, These have movement in three axes with encoders to track the probe position.

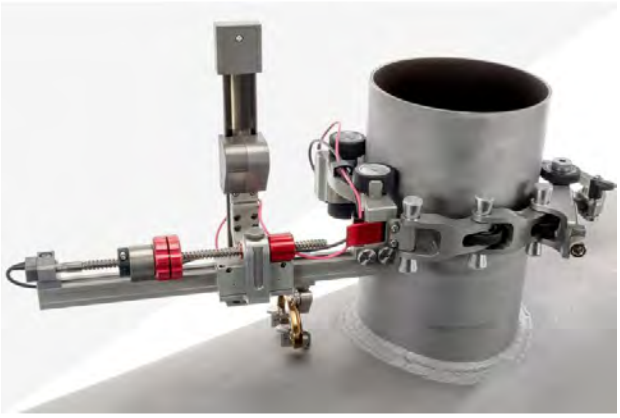


Figure 25 Jireh Rotix 3-Axis nozzle scanner.

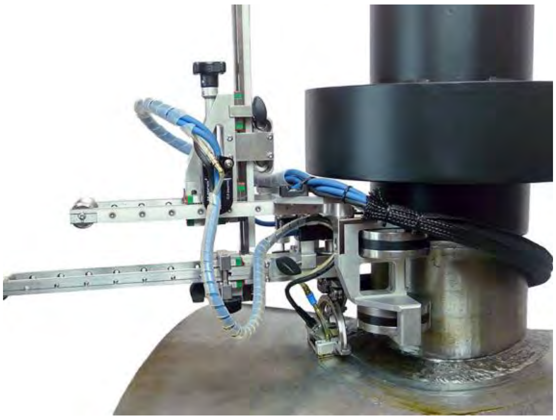


Figure 26 Phoenix NozzleScan

References

Inspection of welded steel joints is covered by ISO 17640-2018, The obsolete British standard BS3923-1:1986, which it replaces, does give significantly more guidance detail on various geometries and may be helpful as a reference.

Images within this document were produced using the Eclipse BeamTool software.

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[i] "Inspection of Nozzles using the Veo+ and Phoenix Nozzle Scan", Sonatest educational note

