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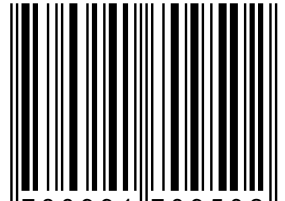
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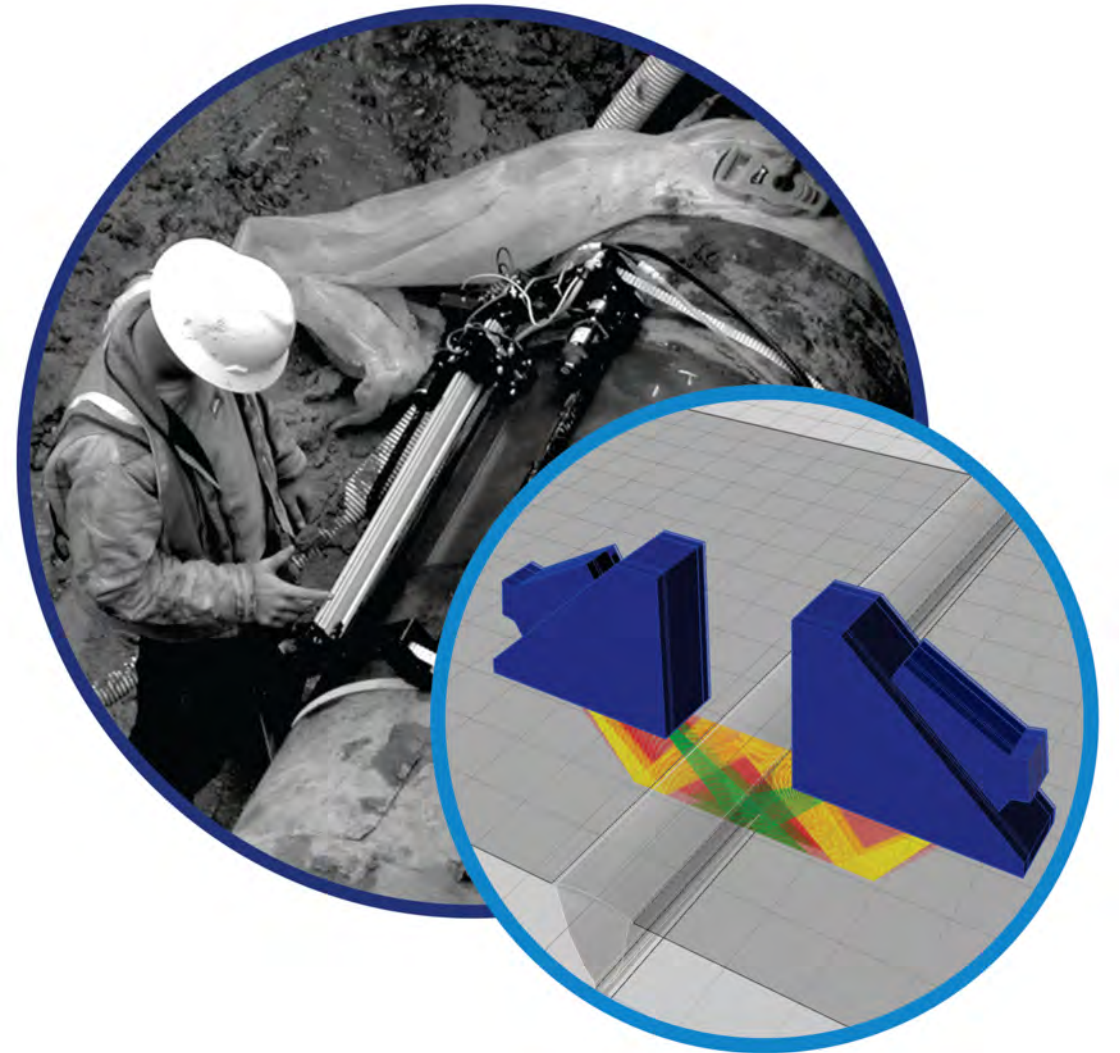
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CHAPTER (11): PHASED ARRAY TECHNIQUE DEVELOPMENT

Having addressed the fundamentals of PAUT and considered the basics of setup (for equipment and sensitivity), the student should now feel comfortable preparing the equipment for inspection. At this time, the student should now be ready to consider how PAUT is applied to various products.

Document aspects of PAUT are a separate topic, but one of the items documented is the technique used. Essentially, the technique development involves assembling all the parameters of the instrument/system and test piece that are required to inspect the specific component (e.g. the steeples in a turbine rotor disc) or generic configuration (e.g. a butt weld in any 25mm thick plate). When confronted by an inspection problem, the operator usually tries to consider the most likely flaw types to occur in the test piece. Or there may be a specific failure mechanism, so a very narrow scope of inspection is required.

Weld inspection is perhaps the most common application of PAUT and a generic inspection would be looking for flaws oriented parallel to the weld centreline. Flaws oriented transverse to the weld axis can occur, but are generally considered to be less common. In fact, some Codes indicate that the use of a transverse scan is not normally a necessity, but something arranged, if deemed a risk. Wording, such as in the Code DNV OS F101 for automated UT on girth welds, is used to identify the special condition if required (from Appendix E of OS F101) *106 "The ultrasonic system shall incorporate facilities for detection of transverse defects, when it is clearly identified that the weld process, parent material, application and environmental condition may increase the risk for transversal type flaws".*

For most weld inspections this means that efforts are concentrated on providing effective beam coverage of the weld volume and heat affected zone (HAZ) for flaws such as lack of fusion, incomplete penetration, slag, porosity and centreline cracking. Transverse flaws are generally rare in most welding processes; however, if there is a requirement for their detection, then options such as matrix arrays with beam skewing capabilities and multiple probe configurations or multiple pass techniques, with probes skewed to direct the beams essentially parallel to the weld axis, can be added.

An operator, preparing for an inspection using phased array equipment, considers the essential parameters in much the same way as for a single element manual scan. Each of the parameters has an equivalent in manual UT scanning (see Table 11.1).

Table 11.1 Essential parameters to consider in technique development

Parameter	Phased Array	Single Element
Angles	Single or a range of angles is available	Only one angle per probe
Apertures	Variable in Active direction fixed in passive	A single probe size is selected
Frequencies	A single frequency per probe	A single frequency per probe
Display	S-scan/E-scan (others)	Only A-scan unless mechanised (but never S-scan)
Manual or Mechanised	May be either	May be either
Part geometry and material	Limitations and obstructions to consider	Limitations and obstructions to consider
	Grain structure effects	Grain structure effects
Surfaces	Surface conditions and surface access	Surface conditions and surface access
Couplant	Brand or type (immersion?)	Brand or type (immersion?)
Instrument make	Simple or complex (just linear arrays or is a 2D matrix required)	Single channel, but may require special features if addressing a custom probe (e.g. very high or low frequency pulser and receiver aspects)
	Any timing or voltage limitations?	
Scan-plan	Direction and extent of scanning and scan patterns that can be used	Direction and extent of scanning
Focusing	Plane, and distance of focal region	A single point or line is possible
Data recording	Generally require full waveform storage	Generally rely on operator recording

Note that when designing a PAUT technique the ability to focus a beam should be something used for only very limited applications. Except for the zonal discrimination technique, welds are rarely inspected using focused beams. For most weld inspection techniques the menu option for focus distance should be entered using a relatively large value (e.g. 500mm) to ensure that the calculated "focal point" is well into the far field.

When a special scan is made requiring the ability of a PAUT system to focus on a region of interest several options of focusing are available. These can be defined based on the plane the focusing is arranged. For narrow-gap welds a vertical projection plane might be considered. For concerns for flaws on the opposite surface focusing might be arranged along a plane at the true depth. A beam that focuses at a constant sound path would be considered to be focused at a specified "half-path" distance. This is the sort of focusing that a mono-element probe would provide (i.e. a single distance

along the sound beam). Or it may be possible to configure a plane of focusing at some specific angle. These various options for focusing in a plane are illustrated in the Figure 11-1.
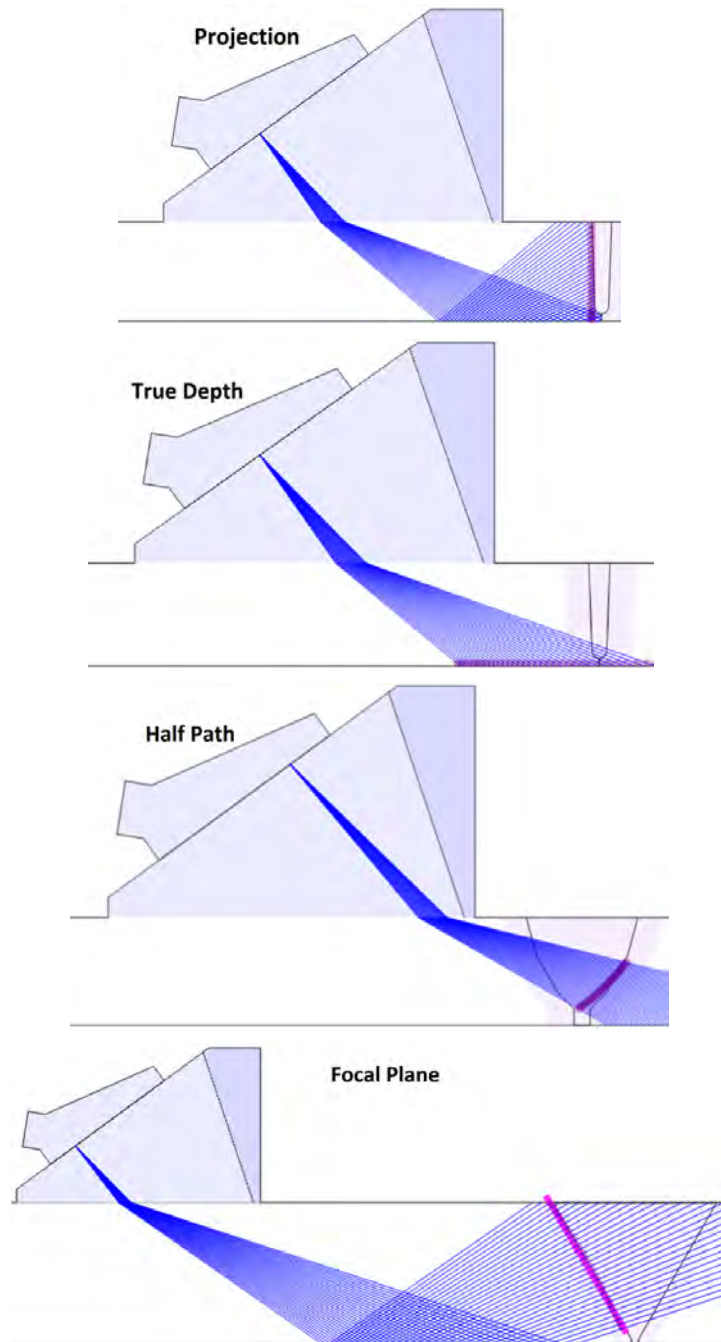
Figure 11-1 Types of focal configurations for linear array probes

11.1   MANUAL OR AUTOMATED APPLICATION OF PAUT

11.1.1   MANUAL PAUT CONFIGURATIONS

A phased array probe can be configured to have a single focal law (one angle), and then it is easily used, as might be any single-element probe used in manual UT, where the operator simply watches the A-scan display. This may be useful in some cases when a project requires a "traditional" manual UT assessment.

Scanning techniques can be developed to use the phased array probe in a hand-held, manually operated raster fashion with a sectorial scan. Then, of course, the operator would monitor the S-scan and use a display that has a top and bottom of test surface indicated on the screen, so as to assist in locating the origins of signals. Although E-scans could be used with manual raster scanning, it would seem to be redundant. It is more likely that the S-scan would be used with manual raster operation of the phased array probe.

Figure 11-2 illustrates an S-scan display with adjustable markers that can be used to indicate the bottom and top of the test piece. With a scale in mm that indicates a distance from the probe, the operator can estimate the depth and approximate position of the source of the signal to make a judgement as to its origin.
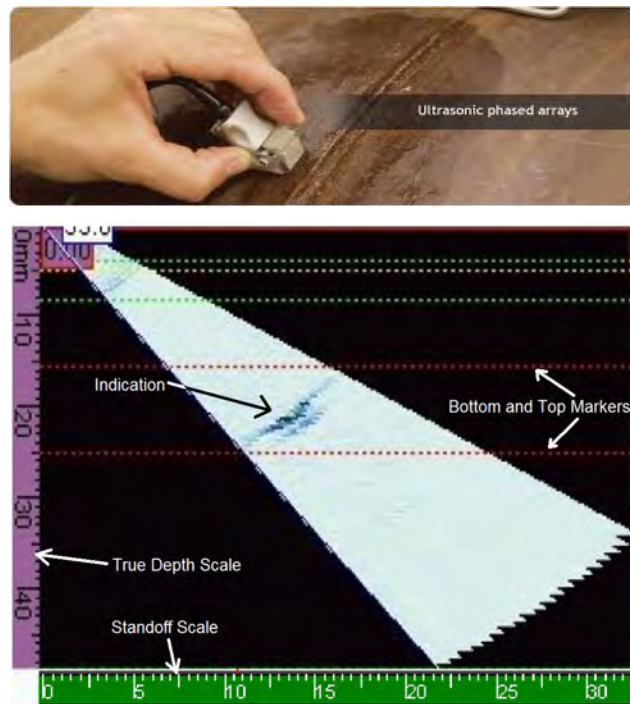
Figure 11-2 Manual scanning using an S-scan to locate indications

11.1.2   AUTOMATED APPLICATIONS OF PAUT

Although it is possible to perform phased array weld inspections using the manual raster motion typical of single element techniques, the greatest advantages of phased array weld inspection are had when using various degrees of mechanisation.

Mechanisation of weld inspections need not be as complex as two or three axes of motion control using motorised actuation. The simplest form of mechanisation would involve connecting an encoder to the phased array probe and moving it along the weld by hand. This simple "line scan" as it is called, has proven to be the most popular option for phased array weld inspections. Even this simple option of a line scan has its degrees of enhancement. Standoff control from a weld when the weld cap is not removed, is sometimes adequate with just the operator sliding the probe as close to the weld as possible. The variations in standoff that result could be relatively small, of the order of 2-3mm. But this can be improved upon, using a straight-edge guide. Magnetic strips work well when inspecting steel components.

Most Standards require that inspection be carried out from both sides of the weld (when possible). When using a single phased array probe, this requires two scans. However, some phased array systems can be arranged to address two phased array probes simultaneously. The phased array instrument must then be configured to collect the data with suitable parameter inputs to ensure that the flaws located are rotated correctly (i.e. skew is 180° different between the two probes). Single and dual phased array mounting with encoders is illustrated in Figure 11-3.
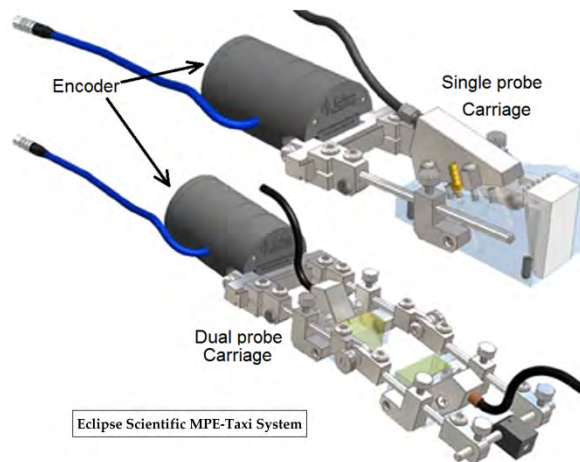
Figure 11-3 Single and dual probe mountings with encoders attached

When used with a guide strip (as in Figure 11-4) the operator has good control on the standoff; and flaw positioning accuracy is significantly improved. Having a solid guide strip to move against also tends to improve the coupling, prevent stuttering motion (which can cause missing data due to excessive speed) and generally speeds up the entire data collection process by avoiding re-scans due to missed data and poor coupling.
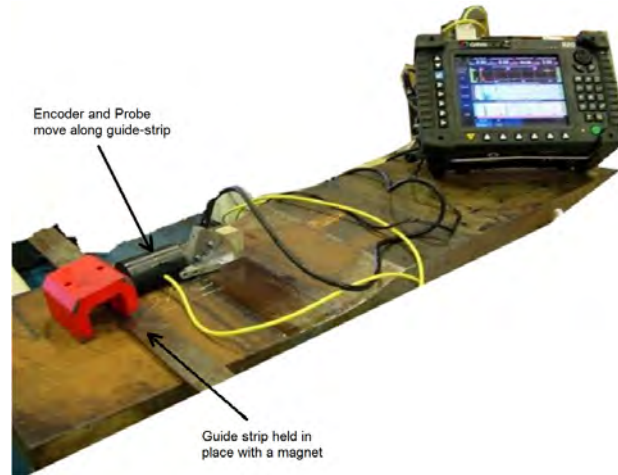
Figure 11-4 Mechanised scanning with a guide strip held in place with a magnet

Motorised motion control with solid mountings can add a further degree of mechanisation to the process. Where high production inspection of a uniformly shaped part is required, (such as pipe girth welds), positioning rings can be used to facilitate rapid mounting and dismounting of the scanning apparatus. The scanning apparatus can be a simple, single or double probe holder, or may be equipped to hold several phased array probes in a single fixture for more complex scanning. (See Figure 11-5)

Small diameter 2 PA probes   Large diameter multi-probe pipe scanner
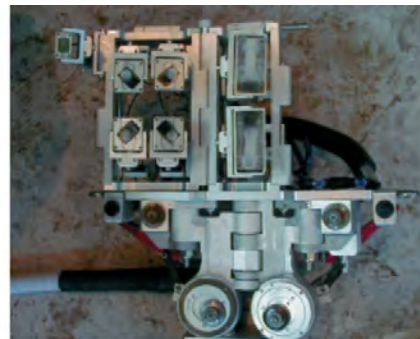
Figure 11-5 Motorised phased array scanners

In Figure 11-5, the image on the left has a quick-connect clam fixture, that the carriage with probes, motor and encoder attach to, for small diameter pipe (typically <12" diameter). On the right in Figure 11-5 is the underside of a system designed for high production pipeline inspections. The drive wheels seen at the bottom of the image connect to a steel band that is clamped in place at the weld. It is often the same band that is used by the automatic welding system to make the weld being inspected. The image shows 2 phased array probes and 4 single element probes (used in T-R mode for transverse flaw detection) plus a thermal sensor (top left) designed to monitor wedge temperature.

11.2 COMPONENT INDUSTRIAL SECTOR

Phased array ultrasonic systems have a wide variety of applications in NDT. Inspection categories can be divided into form or industrial sectors. For example, PAUT has found niches in the railroad, aerospace and power generation industrial sectors. So too, we can discuss how PAUT is used on castings, forgings and welds. Some examples of component form varying the approach can be considered.

11.2.1 RAIL

Railroad components inspected by UT include the track on which the rolling stock moves, and also includes components of the rolling stock such as the wheels and axles. (See Figure 11-6)
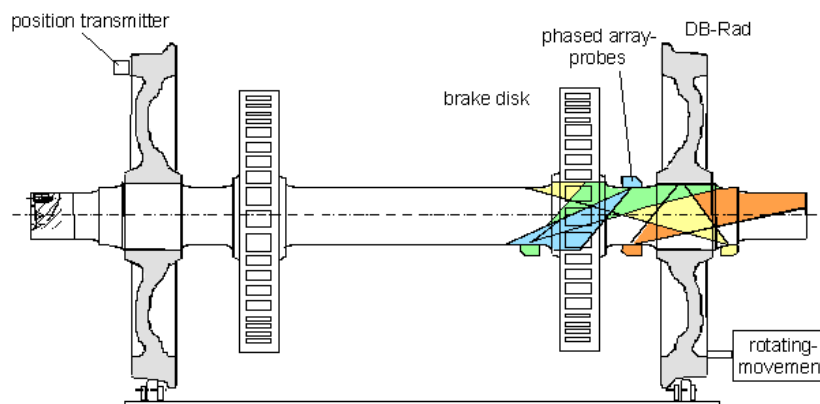
Figure 11-6 PAUT on railroad rolling stock axles [42]

11.2.2 AEROSPACE

Aircraft components (especially military) are subjected to high stresses during flight and landings. Rivet joints can be subjected to corrosive attack as well as high stresses. Phased array UT has been used to assess these components for wear. Figure 11-7 illustrates a carbon fibre composite spar being inspected with a phased array probe with integrated beam-former electronics.
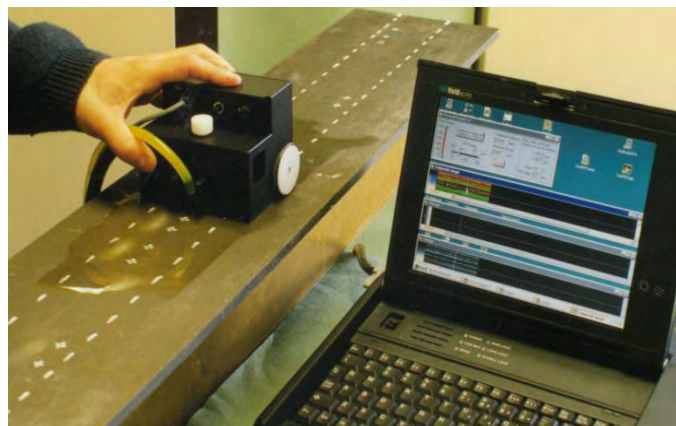
Figure 11-7 PAUT inspection of a carbon fibre composite spar [43]

11.2.3   POWER GENERATION

Fossil fuel, nuclear and even wind-driven generation of electricity all have components that are tested using PAUT, both prior to assembly and as a matter of periodic inspections to assess for wear. Generator components (rotor shafts, turbine disks and turbine blades), boiler tubes and pressure vessel welds are commonly tested in the power generation field. Inspection of the steeple section on a turbine disc is illustrated in Figure 11-8.

Figure 11-8 PAUT on steeple of turbine disc [21]

11.3   COMPONENT FORM

Another way of considering PAUT applications is to look at the form of the product.

11.3.1   CASTINGS

Casting is a primary process. It may be used in many cases as the final shape, if dimensional control is not strict. Generally, the surface is poor and ultrasonic inspections in general are not useful to detect the sort of flaws that occur (flaws like shrinkage and small pores provide weak signals that are difficult to interpret). There is a notable exception in the casting process called the "lost-wax method" or investment casting. This leaves a surface finish that requires little or no added processing. It can be used for a variety of components in several industrial sectors; inlet-outlet valves on nuclear components, rotors on automobile turbochargers, turbine blades that have complex shapes, or airplane parts that have to withstand high temperatures.

11.3.2   FORGINGS

Forgings and extruding parts usually start with a raw form that was cast. A billet or cylindrical casting is then pounded or extruded into a shape. Flaws that existed in the casting will then be flattened and elongated and new flaws can be introduced due to problems in the forging or extruding process. At this stage in the process, detection of relatively large defects is an essentially simple matter for ultrasonic inspections. Checking castings ultrasonically at this stage reduces breakage during further processing, reduces the probability of inherent defects in smaller parts made from forgings, and limits the amount of down time caused by these failures.

11.3.3   PLATE

Plate is a special form of forging. The raw form starts as a billet or bloom (square or rectangular slabs anywhere from 50 to 400mm per side). The raw form is pressed between rollers to reduce the dimension in one direction. As a result, the dimensions in the other directions increase (like rolling out a pizza crust). As with forgings, flaws that existed in the casting will then be flattened and elongated and new flaws can be introduced due to problems in the rolling process. However, as the part decreases in size (in one dimension), it becomes increasingly straightforward to detect the defects contained within the plate using ultrasonics.

11.3.4   WELDING

Plates, forgings and castings may require joining to complete the final form. Fusion welding melts the parent metal and may add more metal, in the form of consumable electrodes, to join the sections of castings, forgings and plates. Flaws are introduced from the welding process and some (like cracking) can occur well away from the weld. The nature and position of flaws in welding is as varied as are the numbers of welding processes. However, weld inspection is usually the most well-known form of ultrasonic inspection, and as a result many techniques exist for detecting the defects caused by the joining process.

11.4   FLAW TYPES

Another option to consider when designing a technique for PAUT is the flaws that are to be sought. For example, not all pipe welds contain the same type of flaw. Electric Resistance Welds (ERW) in pipe-long seams, contain flaws that are unique to the process, so the methods used to detect them will be different than the flaw types associated with submerged arc welding used in the DSAW of long seams on other pipes.

Primary processes (castings) tend to have volumetric flaws (although hot tears would be considered planar). Entrapments of gas or slag or sand, segregation of alloys and the formation of spongiform shrinkage are characteristic of many castings. Such flaws are generally omnidirectional scatterers of incident sound, so they create weak echo signals. Therefore, for most casting work, the technique will need to consider the significant limitations of ultrasonic testing (the same limitations apply to both mono-element and phased array UT).

For forgings and wrought (extruded) products, the flaws tend to be aligned in the direction being worked; and what were volumetric inclusions in the primary form are now flattened and compressed. The operator designing the technique would be advised to know the forming process so as to arrange the beam(s) to be perpendicular to the major axes of these flaws.

Similarly, each welding process can have unique flaw types. GTAW (gas tungsten arc welding) and GMAW (gas metal arc welding) do not use a flux in the welding process. Therefore for these welds, real slag inclusions do not occur. GMAW welds are usually associated with narrow gap bevels with small bevel angles requiring tandem beam paths to detect non fusion. The welding process called friction stir welding, spins around agitator head along the seam where 2 plates are pressed together.

No flux is introduced but the spinning of the heated (melted) metal results in flaws at any orientation. This makes the use of a matrix array advisable, so as to direct the beam in two planes.

Service flaws occur after a component has been fabricated and used. Corrosion, erosion and fatigue cracking are forms of flaws commonly seen due to service wear. The operator designing a PAUT technique should be aware of the environment in which the component was used in order to design a technique that is best suited to detecting the most likely flaws. Figure 11-9 illustrates a phased array probe in a scanner designed to scan around the outer edges of a flange to flange connection, in a pipe product line. On the right is an image made in a polar view indicating that the sealing flange face has been corroded back from the original inside surface of the flange.
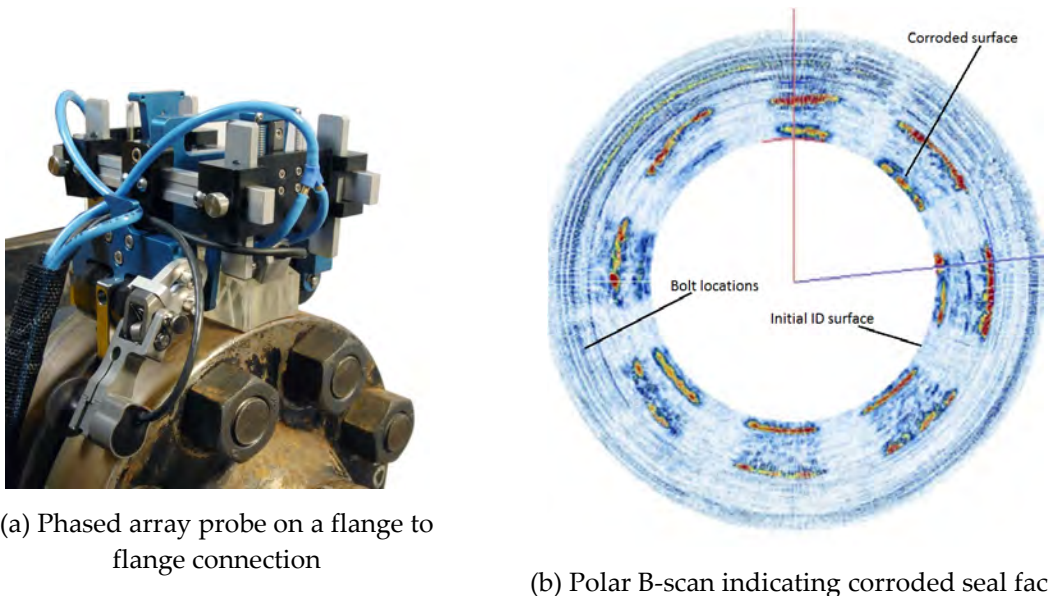
(a) Phased array probe on a flange to flange connection

(b) Polar B-scan indicating corroded seal face

Figure 11-9 Flange to flange phased array scanning

It must be noted that no technique will find all flaws, all the time! In fact, no single NDT method can be used to provide 100% assurance of detecting all flaws. Each method has its advantages and disadvantages and the best that can be done is to identify MOST flaws that MIGHT be considered critical.

To some extent, the techniques developed will need to follow instructions and/or requirements stipulated in Codes, Standard or company specifications. The technique is to conform to the overriding document: there may, however, be some aspects of the technique that the operator has no control over.

11.5   CONTACT OR IMMERSION

11.5.1   IMMERSION

Another option, that the technique designer has, is whether or not to develop the inspection for contact or immersion application PAUT. Small volume, irregular parts or components that are assembled or are on site, would not be considered for immersion testing. Parts with a symmetrical shape that are relatively small may be suitable candidates for immersion testing.

Immersion testing should be defined. Immersion testing is achieved when the part and probe are immersed under water. This has the advantage of maintaining uniform coupling and allows for relatively simple mechanisation.

Shafts and round bar-stock are easily mounted on roller supports that can rotate the part directly under a probe that is advanced along the length of the part.

Flanges and short tubular shapes lend themselves to inspections where the part is rotated on a turntable, as the beam is indexed across the flange surface or upwards along the length, from either the inside or outside surface.

A special immersion case occurs, when the probes can be placed in a fixture under water, while the part is moved past the beams. Figure 11-10 illustrates a tube inspection system where the tube enters a small opening in a "stuffing box" filled with water. Inside the box, four phased array probes are used to provide multi-angle inspections for flaws and to determine wall thickness. The tube need not be spun as would be the case where single element probes are used.
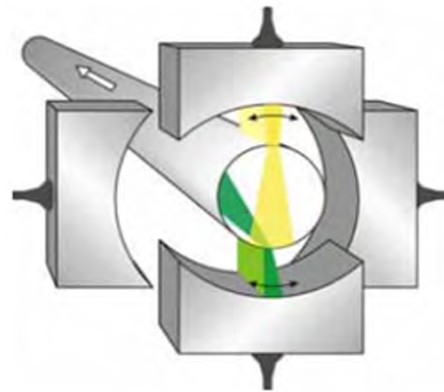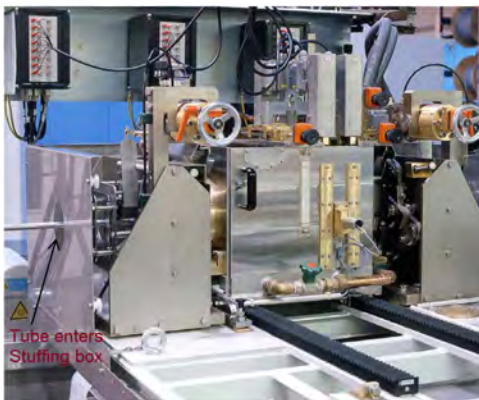

Figure 11-10 Phased array UT tube inspection using a stuffing box [44]

In addition, bubblers, water columns and other special immersion probes also use the same advantages of laboratory immersion testing, but with the added advantage of being portable.

11.5.2   CONTACT

Phased array probes are designed with the intended use in mind. Contact probes can be made with a hard wear-face to be used in direct contact with the test piece (with a thin film of couplant), or can be designed to mount a plastic delay line or refracting wedge. If it is intended that a delay line or refracting wedge be used with the phased array probe, it is NOT advisable to use it in direct contact with a test specimen! Separate packaging is required for immersion applications. The elements and cabling are suitably sealed to prevent water ingress.

11.6   SCAN-PLAN AND ESSENTIAL PARAMETER DETAILS

A requirement of nearly all national or international Standards is the inclusion of a description of the inspection volume coverage of the test piece. This is variously called the "scan-plan", the scanning technique, or the procedure, depending on the terminology used in the specific industrial venue. The "technique" therefore is more of a documentation item. The description of a technique development in this section is not intended to address the documentation aspect of a technique. Instead, we will give consideration to concepts required to design the inspection methodology that might be most suitable for the part to be inspected and the most likely flaws to be detected.

After being presented with the component to be tested, the operator designing the technique considers the equipment, best suited to meet the inspection requirements and then assesses the part for methods to introduce the beams necessary to provide the detection of suspect flaws.

The process can be grouped into two components; volume coverage and instrument settings (essential parameters).

11.6.1   VOLUME COVERAGE AND ANGLE DETAILS

Given a part of a particular material (or materials), the best way for the technique designer to approach the problem of inspection is to identify where the beam must be directed and what access is available on which to place the probe (or surface for beam entry if using immersion).

For a simple geometric shape, it was adequate to use pencil and paper and drafting tools when a single angle was used. However, with the complexity of three dimensional issues when addressing nozzles and the many possible skip options when dealing with the sweep of angles available with S-scans, many users have found it convenient to develop techniques using computer assisted drawings. Several solutions have been developed by different users.

- Spread-sheet programmes have long been able to generate graphics-based line and curve equations.

- Simple ray tracing programmes allow lines representing the centre of beams to be drawn on a basic computer-drawn graphic of the test piece. Some enhancement to these programmes provides information about the beam, such as beam spread, near zones and the ability to represent multiple probes and beams.

- Complex ray tracing programmes have been developed that can be used to configure the entire probe/wedge setup and duplicate beam paths in CAD (computer assisted drafting) images of components in 3D. They can provide computations of the signal characteristics from interactions with flaws that can also be modelled in the software.

- Finite element modelling is perhaps the most complex approach. In addition to considering the characteristics of the transmitted and received impulses, finite element computations use a "mesh-structure" to calculate all aspects of the wave mechanics of the pulse as it moves through the material. This sort of computation is usually so time-consuming that the average operator has little use for it, when designing a technique to address volume coverage of a part.

A significant advantage of the first three options is the ability to export details of the elements used and angles to be generated. With the proper computer protocols, the information can be sent to the phased array instrument and converted into the focal laws that provide the specific delay timings to the elements used.

The intent of all these software options is to provide a visualisation of the beams generated by the phased array system. Generically, we consider this "image" a scan-plan. Typically, the scan-plan would be incorporated into the technique document.

Examples of the options are indicated in the following paragraphs.

In order to streamline the process of zonal discrimination calibrations for girth weld inspections, a modelling tool with a firmware feedback was developed using a spread-sheet format. The girth weld inspection software was designed to allow the operator to design the weld by entering the appropriate values to define the bevel geometry, including defining the number of zones desired. This displays a table of focal law parameters and a graphic representation of the centre of beam rays is provided, indicating where the beam is directed and focused. (See Figure 11-11)
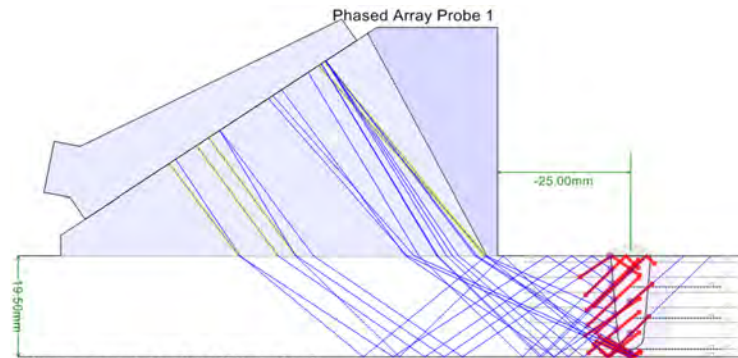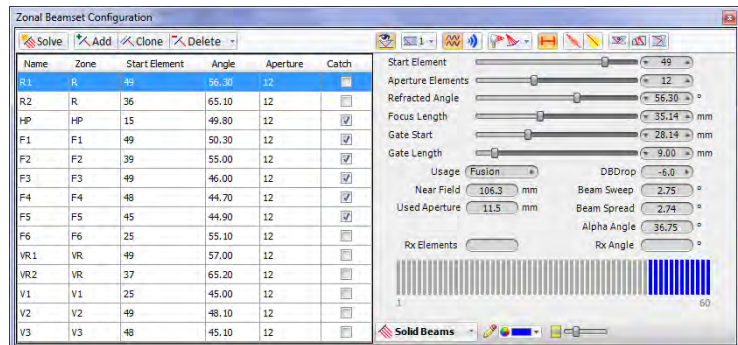
Figure generated using ESBeamTool

Figure 11-11 Spreadsheet-based beam modelling

S-scan inspections of simple butt welds can often be done using a single probe standoff. However, in order for each volume region to have at least two sound beams, at different angles, pass through, usually requires at least two sets of S-scans and a probe with sufficient elements that can provide starting elements in the S scan focal laws that are sufficiently spaced. Optimisation can be made using a very simple ray-trace model indicating the weld bevel with weld cap allowance, heat affected zone and probe/wedge dimensions.

The upper image in Figure 11-12 indicates a 50mm thick plate with a pair of phased array probes on either side, each with two sets of S scans (45°-70°). As indicated in the lower image, a single smaller PA probe could not provide the standoff coverage to achieve the necessary volume and angle coverage (and with a single small probe a total of at least four passes would be required).
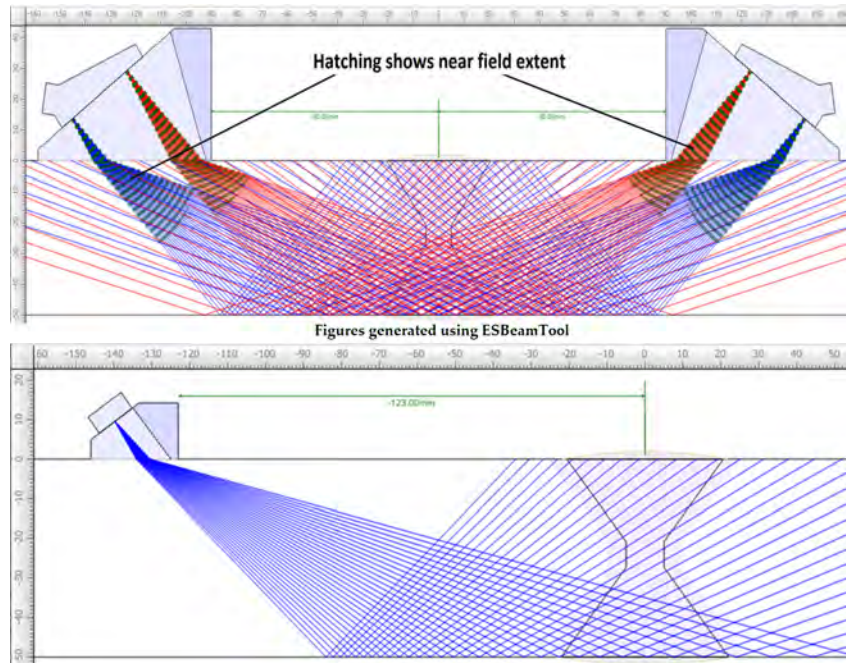
Figure 11-12 Simple Ray Trace Beam Modelling

Figure 11-13 3D CAD image of nozzle with PA probe

More complex ray tracing programmes allow us to place a probe on a 3D CAD image and consider how the rays would interact with the geometry of a complex configuration. Figure 11-13 illustrates the ability to place a phased array probe on a complex nozzle geometry (created in Civa simulation software).

Details of the beam interacting on the flaw, including the A-scan, can also be computed by software; and the S-scan that results, indicated along with the associated A-scans where a flaw can be modelled in the inspected volume. A zoomed-in view of the S-scan overlaid on the component as well as the A-scan that would result with a planar flaw on the inside surface of the set-on nozzle is illustrated in Figure 11-14
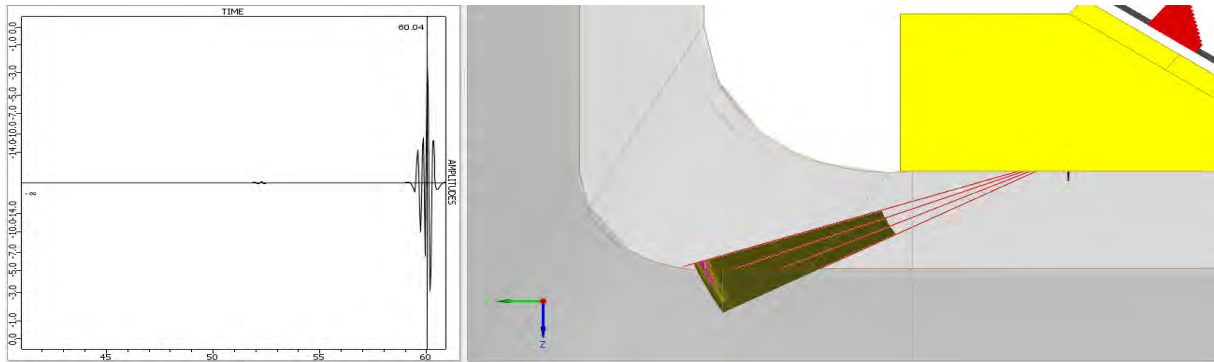
Figure 11-14 A-scan (left) extracted from S-scan (right)

11.6.2   WELD-VOLUME CONSIDERATIONS

Guidance to ensuring suitable volume coverage to inspect a typical butt weld (or similar) should consider the angles used and the extremities of the beam for coverage. Linear and Sectorial scanning patterns are considered.

11.6.2.1 LINEAR (ELECTRONIC) SCAN
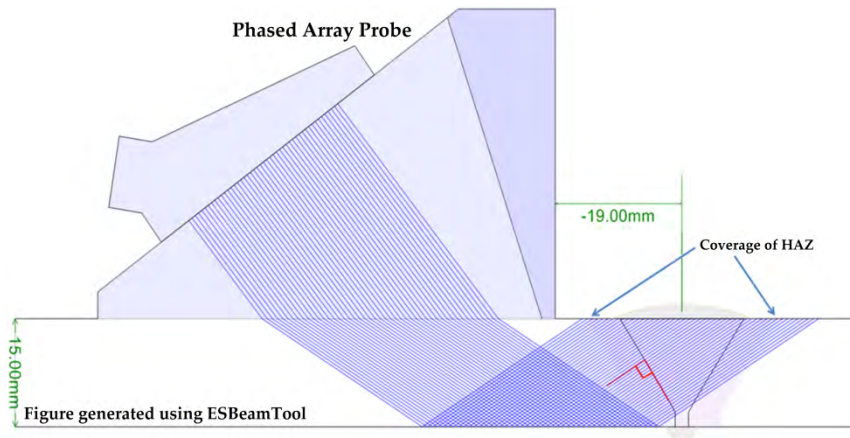
Figure 11-15 Beam positions for E-scan

When configuring the E-scan, an optimum angle is selected to provide near-perpendicular incidence with the bevel profile. The first focal law would have the probe arranged to have the beam intersect the test surface at a point equal to the edge of the HAZ on the near side of the weld.

Ideally a probe is selected with sufficient footprint to provide a beam that will intersect the far side of the weld on the edge of the HAZ. If the probe has insufficient length (elements), the full volume may require multiple scans at decreasing standoffs from the weld centreline.

11.6.2.2 SECTORIAL (AZIMUTHAL) SCAN

When configuring the S-scan, an angle is selected to provide the first focal law to intersect the test surface at a point equal to the edge of the HAZ on the near side of the weld. Since the S-scan uses the same elements, but different delays to obtain different angles, the far side of the weld is addressed by increasing angles until the edge of the HAZ is covered.

Further concerns need to be addressed for S-scans. Sweeping from 30-90° is not feasible since for angles below about 37°, strong compression mode components can result and cause unwanted signals arriving early in time. Similarly, shear mode at 90° is impossible since most of the pressure has converted to a surface wave as we approach 90° (it is very difficult to get practical steering over about 75° for most probes).

A reasonable range respects the steering limits of the probe (typically +/-15°, so the wedge selected must also be considered. A useful wedge has a natural refracting angle of 55° allowing good steering down to 40° and up to 70°. The range of 40-70° refraction provides reasonable volume coverage for many weld designs.
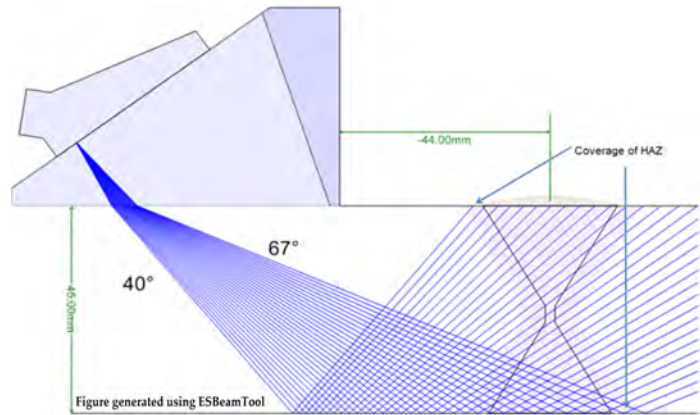
Figure 11-16 Beam positions for S-scan

The exit point for a given focal law may be obtained by determining the surface distance from the front of the wedge to the weld centreline. If the position from the wedge to the centreline doesn't allow both the low and high angles to pass through the weld and HAZ, then two scans will be required (and some standards require at least two S-scans, regardless of coverage in a single pass).
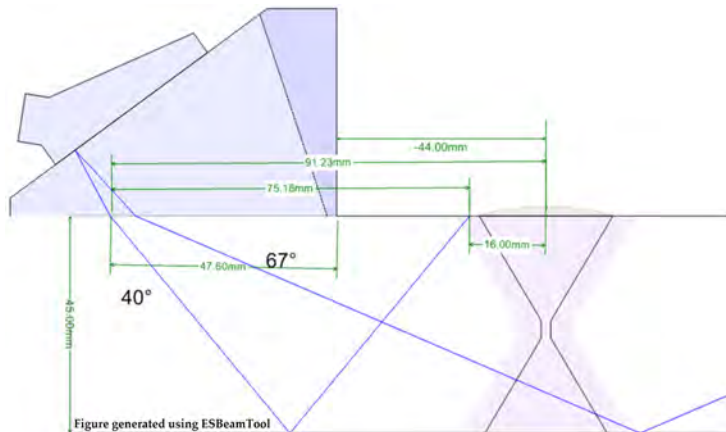
Figure 11-17 Calculating probe position for weld inspection

In order to establish the probe position, some basic guidelines can be followed:

The surface distance for the beam intersecting the surface on the near side of the weld (40° beam in Figure 11-17) is: Surface Distance = 2t x Tan θ; where t is the material thickness and θ is the refracted angle (40°, in this case)

That distance, plus the weld cap and HAZ distance, provides the required standoff of the beam to the centreline of the weld. In the example, it is just over 75mm surface distance plus 16mm for a total of 91mm.

For calculating the standoff distance, the exit point for the beam should be known. The distance from the nose of the wedge to the centre of the first element and also the height of the first element is provided by most wedge manufacturers. Some manufacturers provide the distance from the back of the wedge to the centre of the first element. Then, exit point on the wedge can be calculated using manufacturer data, wedge angle and sound velocity in the wedge.

If the distance from the exit point in the wedge to the surface distance is less than the exit point to the nose of the wedge distance, the start element should be increased or a shorter probe wedge should be selected. This condition will become a concern as the wall thickness decreases and as the weld cap dimension increases.

For most weld conditions, the 40-70° angular sweep can achieve full volume coverage (the example indicates 67° is adequate in the illustrated bevel). However, plate thickness, weld cap size, HAZ distance and probe details can all have a bearing on the results. Each case needs to be dealt with separately.

11.6.3   INSTRUMENTATION SETTINGS

The other component required when developing a technique is an assembly of all the relevant instrument settings. Even here, the pertinent aspects of a phased array probe selection can be assisted using suitable software.

By modelling the performance of a particular set of elements and wedge configurations, it is possible to see if there are any limitations to beam steering, with a particular probe selected for a technique.

Figure 11-18 shows that a strong shear wave grating lobe has formed as the probe design attempted to minimise the number of elements (16) and increase the aperture (0.5mm gaps and 1mm element widths).
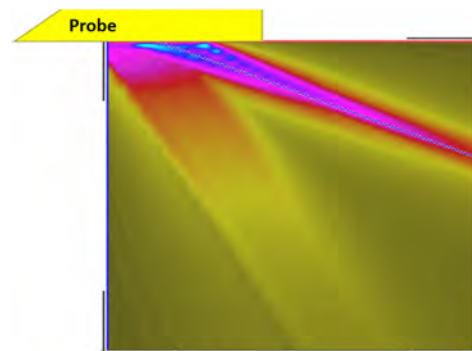

Figure 11-18 Poor steering capability forms grating lobes

Identifying parameters of the probe and instrument become necessary essentials when designing a technique so these must be listed with specific values or ranges of suitable values. Table 11.2 indicates items that become essential parameters in a PAUT technique.

Sufficient parameters should be identified, such that any subsequent operator could set up an inspection that is identical to the first inspection and obtain nearly identical results to the first inspection.

Table 11.2 Essential parameters in technique design

Probe	Number of elements
	Element width (height)
	Element length
	Kerf (gap)
	Element pitch
	Nominal frequency
Wedge	Material
	Wedge material velocity
	Incident angle
	Height of ref. element over test piece
Instrument	Make/model
	Pulser voltage (volts)
	Pulse voltage shape
	Pulse duration
	Receiver frequency settings
	Processing settings (smoothing, compression, averaging)
Beam-setups	Scan type (fixed, E-scan, S-scan)
	Number of elements in focal law
	Start element
	Step increment (angle or elements)
Test mechanics	Immersion or contact
	Scan type (manual/mechanised/motorised)
	Scanning pattern (line, raster, helical)
Materials	Test piece material (and velocities)
	Couplant
	Geometry (thickness, shape)
	Scan surface
Reference	Reference blocks and targets