Phases array use in industry:

Phased array is widely used for non destructive testing (NDT) in several industrial sectors, such as construction, pipelines, and power generation. This method is an advanced NDT method that is used to detect discontinuities i.e. cracks or flaws and thereby determine component quality. Due to the possibility to control parameters such as beam angle and focal distance, this method is very efficient regarding the defect detection and speed of testing. Apart from detecting flaws in components, phased array can also be used for wall thickness measurements in conjunction with corrosion testing. Phased array can be used for the following industrial purposes:

- Inspection of welds
- Thickness measurements
- Corrosion inspection
- PAUT Validation/Demonstration Blocks[5]
- Rolling stock inspection (wheels and axles)
- PAUT & TOFD Standard Calibration Blocks

Feature of phased array:

- The method most commonly used for medical ultrasonography.
- Multiple probe elements produce a steerable and focused beam.[6]
- Focal spot size depends on probe active aperture (A), wavelength (γ) and focal length (F).[7] Focusing is limited to the near field of the phased array probe.
- Produces an image that shows a slice through the object.
- Compared to conventional, single-element ultrasonic testing systems, PA instruments and probes are more complex and expensive.
- In industry, PA technicians require more experience and training than conventional UT technicians.

Specification of phased array:

Number of Pulsers: Will define the maximum number of elements that can be grouped to form an active aperture or virtual prob aperture.

Number of Receivers: Will define the total number of elements that can be used for sequencing apertures that leads To the potential increase in coverage from a single probe footprint.

XX:YY: Naming convention used where XX = Number of pulsers and YY= Number of receiver paths. The number of receivers is always greater or equal to number of pulsers. Instruments from 16:16 to 32:128 are available in field portable packaging. Higher pulser and receiver combinations are available for in-line inspection and/or systems that Use larger element count probes.

Focal Laws: The number of focal laws that can be combined to form an image is often specified. In general, higher XX:YY configurations can support more focal laws as they support greater element apertures and/or more aperture stepping in linear scanning. Note that more focal laws does not always mean more functionality. Take the example below using a 64 element probe performing a sectorial scan of three side-drilled holes from 40 to 70 degrees, comparing steering with 1 degree (30 laws), 2 degree (15 laws), and 4 degree (7 laws) steps over a 2 inch, 50 mm metal path. While the image will be slightly better defined with finer angle increments, detection at coarser resolution is adequate. Unless beam diameter is drastically reduced with focusing, sizing from images will not dramatically change either.

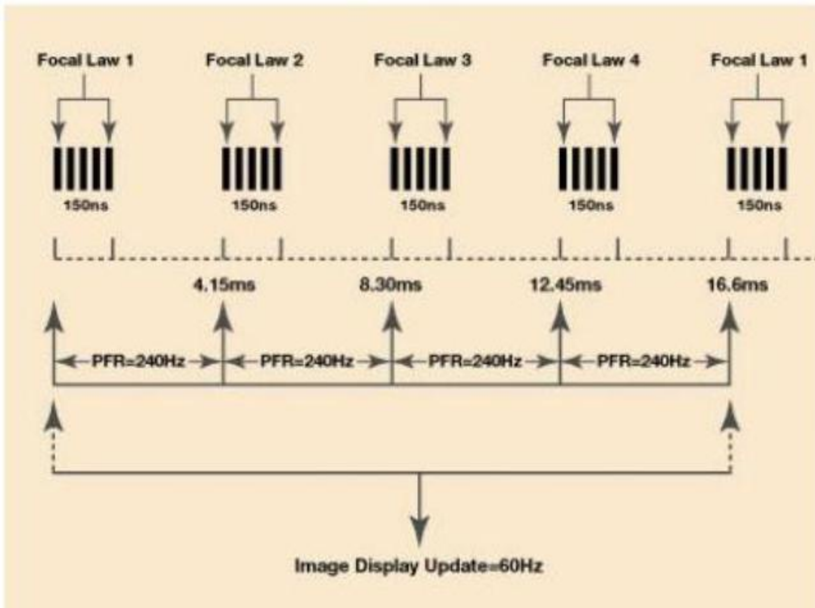
Examples for the number of focal laws required performing linear scans with varying combinations of virtual probe apertures and total element counts are shown below.

LINEAR E-SCAN

Aperture	Total Elements	Element Step	# Laws
4	16	1	13
8	16	1	9
4	32	1	29
8	32	1	25
16	32	1	17
4	64	1	61
8	64	1	57
16	64	1	49
8	128	1	121
16	128	1	113
8	256	1	249
16	256	1	241

From the above, it is readily apparent that a 16:16 configuration used with a 16 element transducers may only require 30 laws while a 16:128 or 32:128 instrument configuration used in linear scan mode with a 128 element transducer may very well require 128 focal laws.

An example of a reduced four focal law linear scan sequence with a 60 Hz image display update is shown below for conceptualization.



The actual image display rate may be affected by other parameters. The A-scan refresh rate of a single focal law will vary between instruments. In some instruments, the A-scan PRF rate is limited by the maximum image display update, whether it is shown with the phased array image or even when maximized to a full A-scan. For this reason, in some applications it may be important to verify A-scan PRF when derived from focal law sequence in various image display modes.

Probe recognition: The ability to recognize phased array probes reduces operator setup time by automatically configuring an instrument setup with proper number of elements and probe geometry.

Image types: Sectorial and linear scans are typically available in phased array instruments. The ability to stack these image modes to create amplitude and depth C-scans allows planar images to be formed and provides expanded means for sizing defects.

Waveform storage: The ability to store raw RF waveforms allows data to be reviewed off line. This is particularly useful when collecting data over a large area.

Multi-Group support: More capable phased array instruments allow multiple focal law groups to be sequenced on one or more connected transducers. This is especially useful in cases where it is important to collect volumetric data which will be analyzed off line. For example, a 5 MHz, 64 element probe can be programmed to use elements 1-16 for a 40 to 70 degree sector scan, while a second group can be used to perform a 60 degree linear scan with an aperture of 16 elements, stepping by one element over the entire 64 element length.

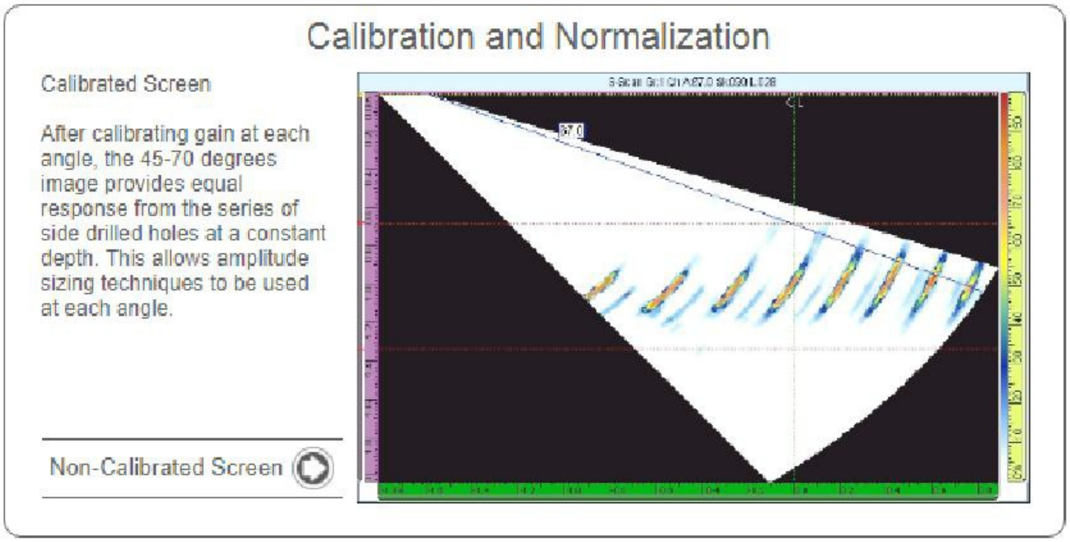
Encoding: There are two classes of instruments generally available: manual and encoded.

A manual phased array instrument works much like a conventional flaw detector as it provides real time data. Along with an A-scan, the instrument also shows real time S-scan or linear scan images which can aid in detection and discontinuity analysis. The ability to use and visualize more than one angle at a time in a test would be the main reason for using this type of instrument. In some cases like crack sizing, the image can be used as a tool to help size crack depth.

A phased instrument with encoder interface merges probe positional data, probe geometry, and programmed focal law sequences to allow top, end and side view images of test specimen. In instruments that also store full waveform data, images can be reconstructed to provide cross sectional views along the length of the scan or regenerate planar C-scans at various levels. These encoded images allow for planar sizing of defects.

Reference Cursors: Instruments will provide various cursors that can be used on an image for direct sizing. In a sectorial scan, it is possible to use cursors for measurement of crack height. Approximate defect size can be measured in encoded linear C-scans as well.

Calibration Method: The method of calibration for phased array transducers can be varied. As beam formation relies on variant element delays and groups, it is important to normalize the response from each focal law, to compensate both for element-to-element sensitivity variations in the array transducer and for varying wedge attenuation and energy transfer efficiency at different refracted angles. Calibration of wedge delay and sensitivity over the entire inspection sequence not only provides clearer image visualization, but also allows measurement and sizing from any focal law. While Olympus NDT instruments allow full calibration, many instruments will only allow calibration of one focal law at any one time.



TVG/DAC for phased array: For sizing defects, A-scan amplitude techniques using DAC curves or time corrected gain are common. These methods account for material attenuation effects and beam spreading by compensating gain levels (TCG) or drawing a reference curve based on same size reflector response as a function of distance. As in sensitivity calibrations, some instruments allows a TCG to be built at multiple points over all defined focal laws. In these instruments, the view can be switched from TCG to DAC curve at any time. This allows use of sizing curves at multiple angles for sectorial scans or at any virtual aperture in linear scans.

Some phased array instruments also provide a conventional ultrasonic channel to support inspections with single element transducers. It is important to know how this conventional channel functions.

Pulser: Because of the small size of phased array elements, and leveraging the fact that constructive interference effects between elements results in higher sensitivity, phased array pulsers are typically limited to 100 volts. Often vendors use this limited phased array pulser as the conventional transducer pulser. This can become very limiting in applications involving long sound paths or highly attenuating materials, especially when using frequencies at or below 2.25MHz.

Image Support: While the phased array portion of the instrument supports A-scan, B-scan, C-scan, and sectorial scans, this does not mean the conventional UT portion of the instrument will necessarily incorporate any imaging. More capable instruments do allow cross sectional B-scans on a timed basis with waveform storage on the conventional side. Some also include the ability to interface with conventional transducers attached to one or two axis encoded scanners to generate actual position related B-scans and C-scans respectively. Of course sectorial scanning is unique to phased array.

In the image below, a combined phased array/conventional instrument is working in conventional mode. performing a

B-scan of a corroded pipe with a dual element transducer in an encoded hand scanner.

Fig : phased array Testing

Anatomy of Phased Array Display

This section provides further insight into how phased array images are constructed. In particular, it will further explain required inputs, and the relationships of the various phased array display types with respect to the actual probe assembly and part being inspected. We will also explain the typically available A-scan views associated with the phased array image.

Required Considerations for Proper Inspection

As discussed previously, there are many factors that need to be identified in order to properly perform any ultrasonic inspection. In summary, there are material specific characteristics and transducer characteristics needed for calibrating the instrument for a proper inspection.

Material:

1. Velocity of the material being inspected needs to be set in order to properly measure depth. Care must be taken to select the proper velocity mode (longitudinal or shear). As you may recall, compressional straight beam testing typically uses longitudinal waves while angle beam inspection most often uses shear wave propagation.
2. Part thickness information is typically entered. This is particularly useful in angle beam inspection. It allows proper depth measurement relative to the leg number in angle beam applications.
3. Radius of curvature should be set considered when inspecting non-flat parts. This curvature can be algorithmically accounted for to make more accurate depth measurements.

Transducer:

1. Frequency must be known to allow for proper pulser parameters and receiver filter settings.
2. Zero Offset must be established in order to offset electrical and mechanical delays resulting from coupling, matching layer, cabling and electronic induced delays for proper thickness readings.
3. Amplitude response from known reflectors must be set and available for reference in order to use common amplitude sizing techniques.
4. Angle of sound beam entry into the material being inspected.
5. For phased array probes, the number elements and pitch need to be known.

Wedge:

1. Velocity of sound propagation through the wedge
2. Incident angle of the wedge.
3. Beam index point or front of probe reference.
4. First element height offset for phased array.

In conventional ultrasonic testing, all of the above steps must be taken prior to inspection to achieve proper results. Since a single element probe has a fixed aperture, the entry angle selection, zero offset, and amplitude calibration are specific to a single transducer or transducer/wedge combination. Each time a transducer or its wedge is changed, a new calibration must be performed.

Using phased array probes, the user must follow these same principles. The main advantage of phased array testing is the ability to change aperture, focus, and/or angle dynamically, essentially allowing the use of several probes at one time. This imparts the additional requirement of extending calibration and setup requirements to each phased array transducer state (commonly referred to as a focal law). This not only allows accurate measurements of amplitude and depth across the entire programmed focal sequence, but also provides accurate and enhanced visualization via the natural images that phase array instruments produce.

One of the major differences between conventional and phased array inspections occurs in angle beam inspection. With conventional UT, input of an improper wedge angle or material velocity will cause errors in locating the defect, but basic wave propagation (and hence the resultant A-scan) is not influenced, as it relies solely on mechanical refraction. For phased array however, proper material and wedge velocities along with probe and wedge parameter inputs are required to arrive at the proper focal laws to electronically steer across the desired refracted angles and to create sensible images. In more capable instruments, probe recognition utilities automatically transfer critical phased array probe information and use well-organized libraries to manage the selection of wedge parameters.

The following values must normally be entered in order to program a phased array scan:

Probe Parameters

Frequency

Bandwidth

Size

Number of elements

Element pitch

Wedge Parameters:

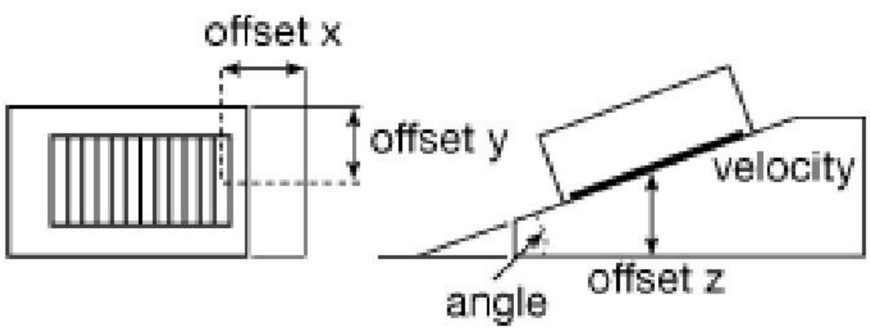
Incident angle of the wedge

Nominal velocity of the wedge

Offset Z = Height to center of first element

Index offset X = distance from front of wedge to first element

Scan offset Y = distance from side of wedge to center of elements

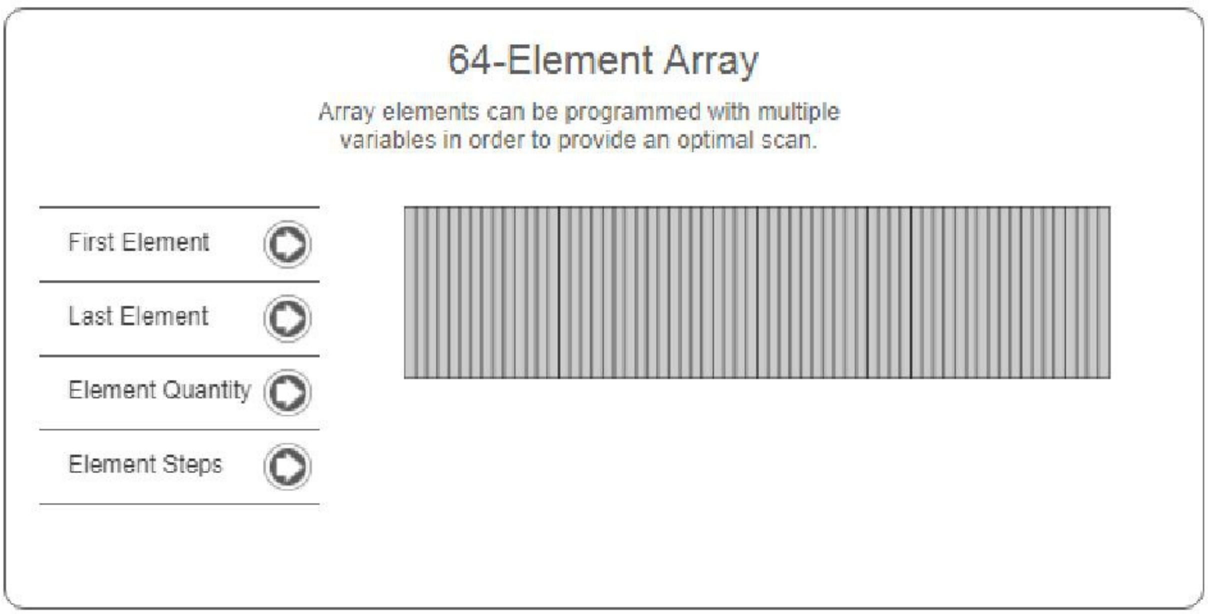


Focal Law Setup:

To gain the full advantages of linear array scanning, typically a minimum of 32 elements are used. It is even more common to use 64 elements. More elements allow larger apertures to be stepped across the probe, providing greater sensitivity, increased capacity of focusing and wider area of inspection. The instrument must have the basic probe and wedge characteristics entered, either manually or via automatic probe recognition. Along with typical UT settings for the pulser, receiver and measurement gate setup, the user must also set transducer beam and electronic steering (focal law) characteristics.

Required User inputs:

- Material Velocity
- Element Quantity (the number of elements used to form the aperture of the probe)
- First element to be used for scan
- The last element in the electronic raster
- Element step (defines how defined aperture moves across the probe)
- Desired focus depth, which must be set less than near field length (N) to effectively cerate a focus
- Angle of inspection



Straight Beam Linear scans:

Straight beam linear scans are usually easy to conceptualize on a display because the scan image typically represents a simple cross-sectional view of the test piece. As described in Section 3.7, a phased array system uses electronic scanning along the length of a linear array probe to create a cross-sectional profile without moving the transducer. As each focal law is sequenced, the associated A-scan is digitized and plotted. Successive apertures are "stacked", creating a live cross sectional view. The effect is similar to a B-scan presentation created by moving a conventional single element transducer across a test piece and storing data at selected intervals.

In practice, this electronic sweeping is done in real time so a live part cross section can be continually viewed as the transducer is physically moved. The actual cross section represents the true depth of reflectors in the material as well as the actual position typically relative to the front of the probe assembly. Below is an image of holes in a test block made with a 5L64-A2, 64-element 5 MHz linear phased array probe. The probe has a 0.6mm pitch.

In this example, the user programmed the focal law to use 16 elements to form an aperture and sequenced the starting element increments by one. So aperture 1 consists of elements 1 through16, aperture 2 from elements 2 through 17, aperture 3 from elements 3 through18, and so on. This results in 49 individual waveforms that are stacked to create the real time cross-sectional view across the transducer's length.

The result is an image that clearly shows the relative position of the holes within the scan area, along with the A-scan waveform from a single selected aperture, in this case the 29th aperture out of 49, formed from elements 29-45, is represented by the user-controlled blue cursor. This is the point at which the beam intersects the second hole

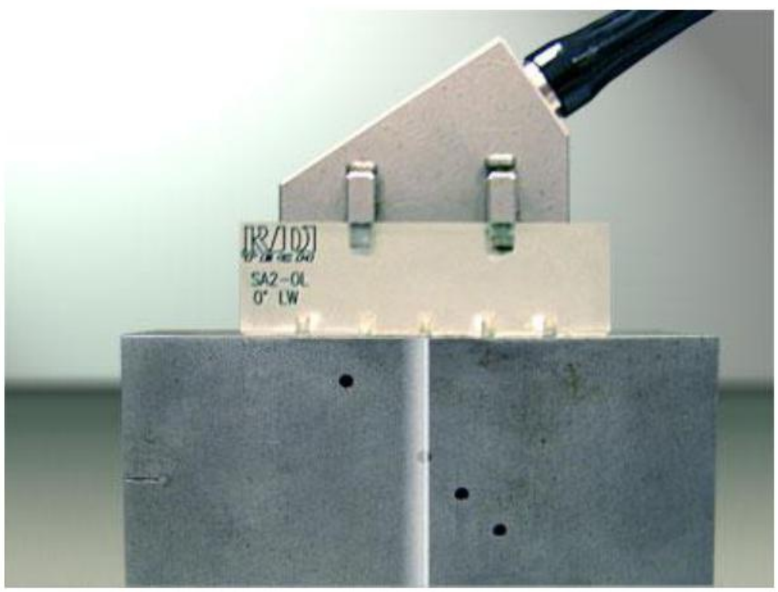
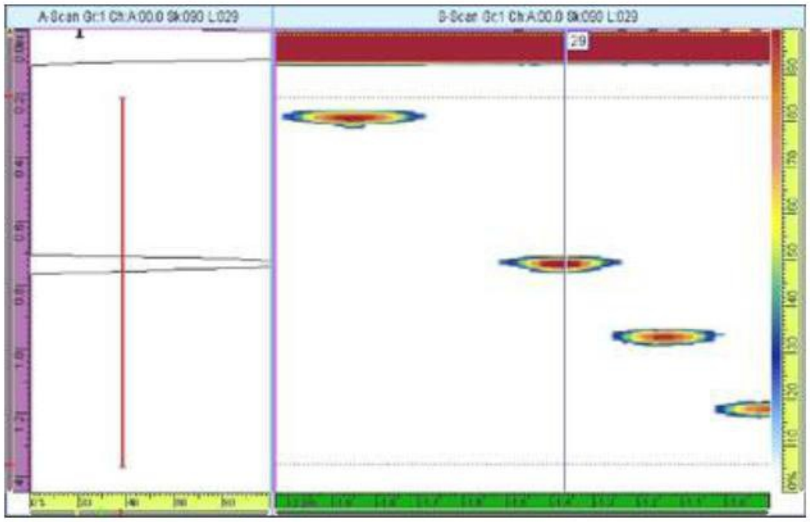
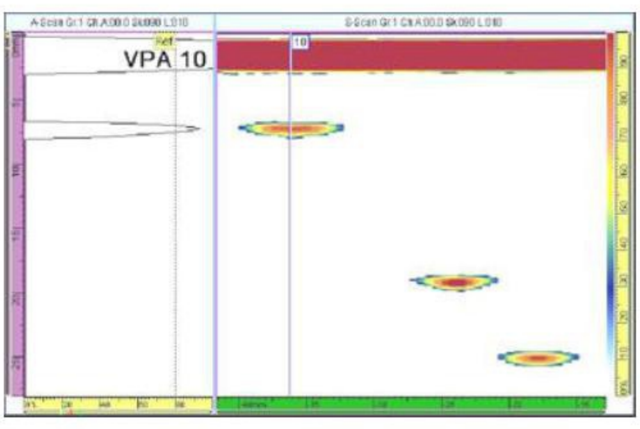


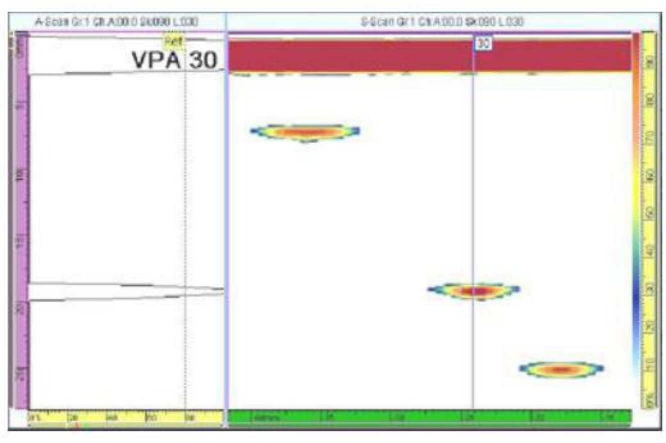
Fig : Straight Beam Linear scans



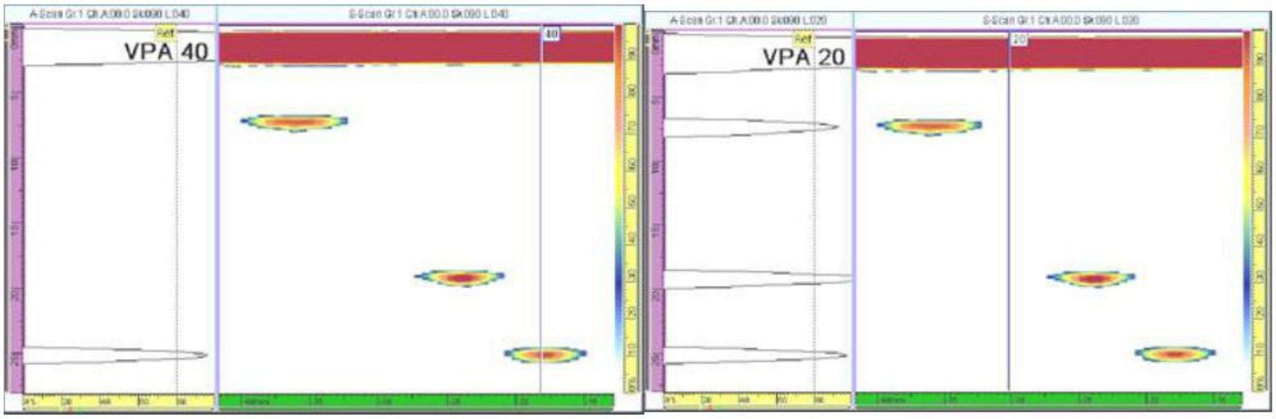
The vertical scale at the left edge of the screen indicates the depth or distance to the reflector represented by a given peak in the A-scan. The horizontal scale of the A-scan indicates relative echo amplitude. The horizontal scale under the scan image shows reflector position with respect to the leading edge of the probe, while the color scale on the right edge of the screen relates image color to signal amplitude.

Alternately, the instrument can be set to display an "all laws" A-scan, which is a composite image of the waveforms from all apertures. In this case, the A-scan includes the indications from all four holes within the gated region. This is particularly useful mode in zero degree inspections, although it can also be confusing when working with complex geometries that produce numerous echoes. In the example below, the first three screens show views in which the A-scan display depicts the waveform from a single virtual probe aperture in the scan, each of which is centered over one of the reference holes.





This fourth screen shows an all laws A-scan in which the signals from all apertures is summed, thus showing all three hole indications simultaneously.



A-scan source mode on some more advanced instruments allows the A-scan to be sourced from the first or maximum signal within the gated region.

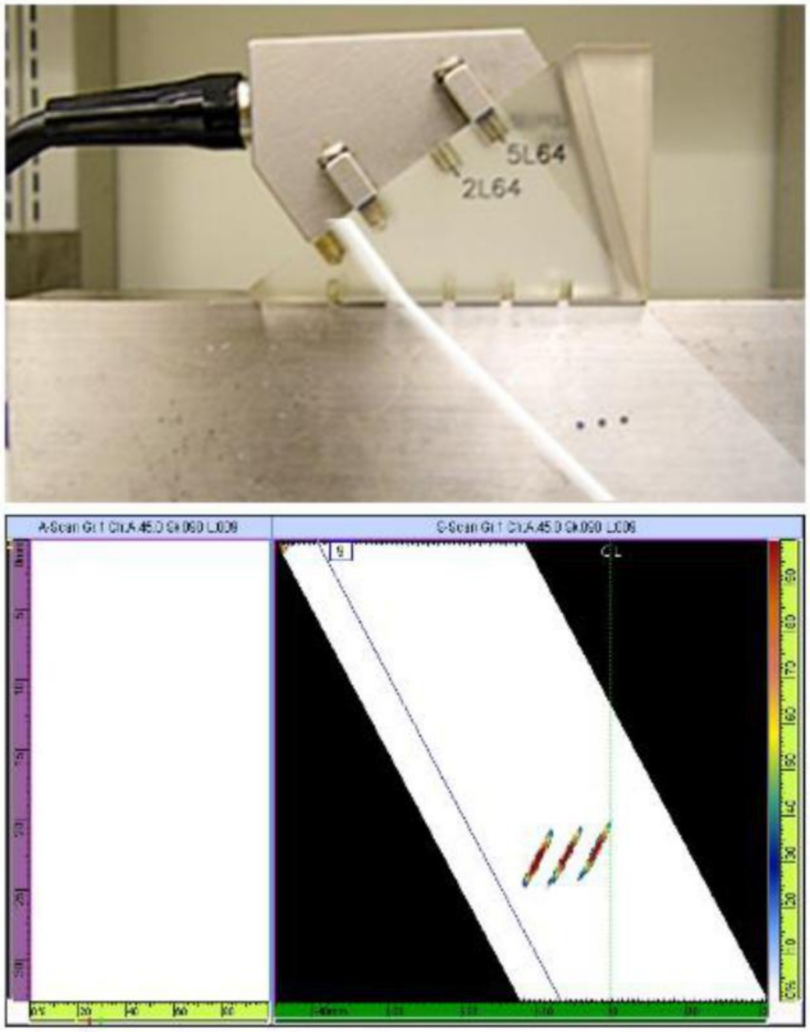
Leak testing:

It is conventional to use the term "leak" to refer to an actual discontinuity or passage through which a fluid flows or permeates. "Leakage" refers to the fluid that has flown through a leak. "Leak rate" refers to the rate of fluid per unit of time under a given set of conditions, and is properly expressed in units of mass per unit time. Modern leak testing is thus based on the notion that all containment systems leak, the only rational requirement that can be imposed is that such systems leak at a rate no greater than some finite maximum allowable rate, however small that may be as long as it is within the range of sensitivity of a measuring system.

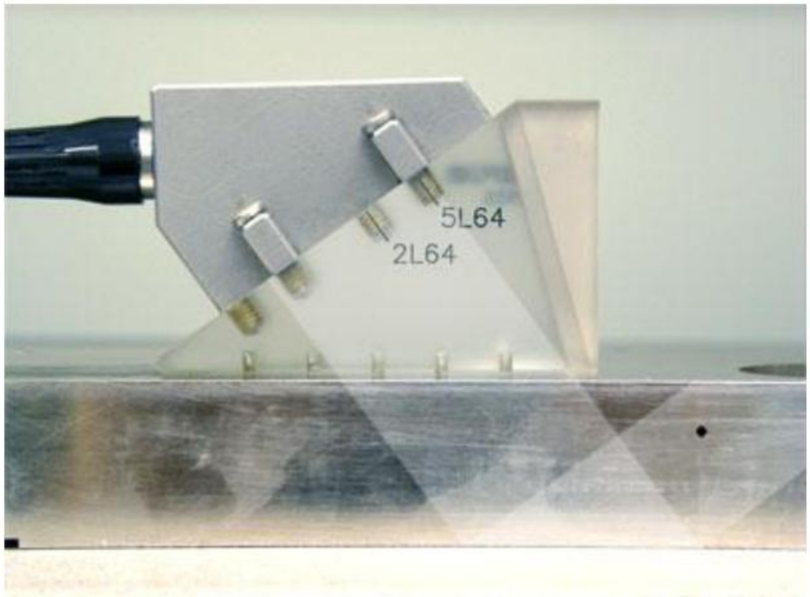
Angled Linear Scans:

A linear scan can also be programmed at a single fixed angle, much like the beam from a conventional single element angle beam transducer. This single-angle beam will scan across the length of the probe, allowing the user to test a larger width of material without moving the probe. This can cut inspection time, especially in weld scanning applications.

Angled Linear Scan



In the example above, the beam is sweeping across the test piece at a 45 degree angle, intercepting each of three holes as it moves. The beam index point, the point at which the sound energy exits the wedge, also moves from left to right in each scan sequence. The A-scan display at any given moment represents the echo pattern from a given aperture. In any angle scan not involving very thick materials, it is also necessary to consider the actual position of reflectors that fall beyond the first leg, the point at which the beam first reflects from the bottom of the test piece. This is usually a factor in tests involving typical pipes or plates. In the case below, as the beam scans from left to right, the beam component from the center of the probe is reflecting off the bottom of the steel plate and hitting the reference hole in the second leg.



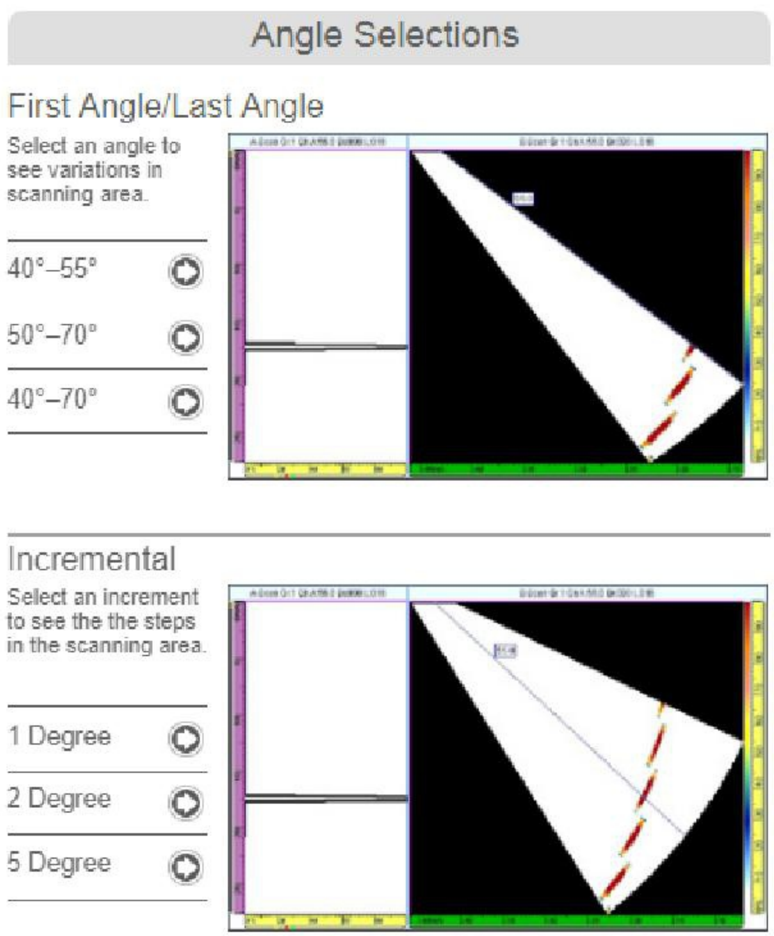
The screen display has been set up to show by means of the dotted horizontal cursors the relative positions of the end of the first leg and the end of the second leg on the image. Thus, this hole indication, which falls between the two horizontal cursors, is identified as being in the second beam leg. Note that the depth scale on the left edge of the screen is accurate only for the first leg. To use the scale beyond that, a correction must be applied. In the second leg, it is necessary to subtract the apparent depth as read off the scale from twice the thickness of the test piece to get the true depth of an indication. For example, in this case the actual depth of the second leg indication in the 25 mm thick plate is 38 - (2 x 25), or 12 mm. In the third leg, it is necessary to subtract twice the thickness of the test piece from the apparent depth of the indication to obtain true depth.

Focal Law Sequence:

This is very similar to the linear scan setup described in Section 5.1 in that the parameters listed there must be entered, except that a range of angles must also be selected. All of the other considerations listed in section 5.1 apply. Along with typical UT settings for pulser, receiver and measurement gate setup, the user must also set transducer beam and electronic steering (focal law) characteristics.

Required User inputs:

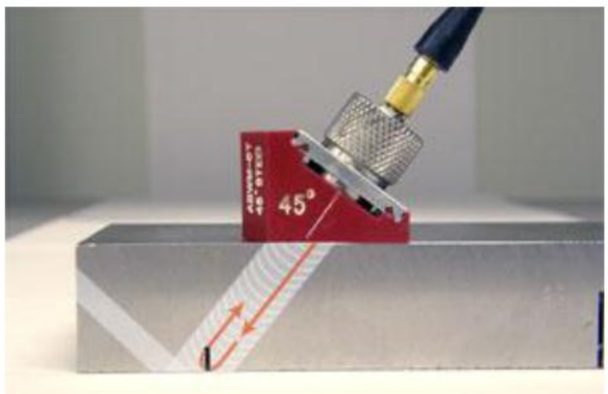
- Material Velocity
- Element Quantity (the number of elements used to form the aperture of the probe)
- First element to be used for scan
- The last element in the electronic raster
- Element step (defines how defined aperture moves across the probe)
- The first angle of the scan.
- The last angle of the scan.
- The increment at which angles are to be stepped.
- Desired focus depth, which must be set less than near field length (N) to effectively cerate a focus

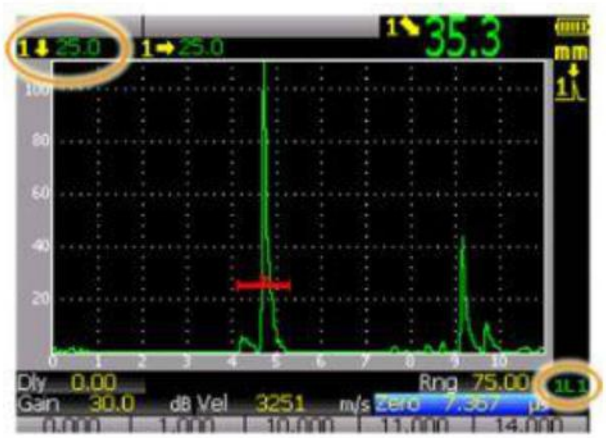


Interpreting Sector Scans

In the case of swept angle sector scans, interpretation can be more complex because of the possibility of multiple leg signals that have reflected off the bottom and top of the test piece. In the first leg (the portion of the sound path up through the first bounce off the bottom of the part), the display is a simple cross-sectional view of a wedge-shaped segment of the test piece. However beyond the first leg, the display requires more careful interpretation, as it also does when using a conventional flaw detector.

A conventional flaw detector used with common angle beam assemblies displays a single-angle A-scan. Modern digital instruments will use trigonometric calculation based on measured sound path length and programmed part thickness to calculate the reflector depth and surface distance. Part geometry may create simultaneous first leg and second leg indications on the screen, as seen here in the case below with a 5 MHz transducer and a 45 degree wedge, where a portion of the beam reflects off the notch on the bottom of the part and a portion reflects upward and off the upper right corner of the block. Leg indicators and distance calculators can then be used to confirm the position of a reflector.





The first leg indication is a large reflection from the notch on the bottom of the test block, The depth indicator (upper left of screen image) shows a value corresponding to the bottom of a 25 mm thick block, and the leg indicator (lower right of screen image) shows that this is a first leg signal.

The second leg indication is a small reflection from the upper corner of the block. The depth indicator shows a value corresponding to the top of a 25 mm thick block, and the leg indicator shows that this is a second leg signal. (The slight variation in depth and surface distance measurements from the expected nominal values of 0 and 50 mm respectively is due to beam spreading effects).

When the same test is performed with a 5 MHz phased array probe assembly, scanning from 40 to 70 degrees, the display shows a sector scan that is plotted from the range of angles, while the accompanying A-scan typically represents one selected angular component of the scan. Trigonometric calculation uses the measured sound path length and programmed part thickness to calculate the reflector depth and surface distance at each angle. In this type of test, part geometry may create simultaneous first leg and second leg indications on the screen as well as multiple reflectors from a single angle. Leg indicators in the form of horizontal lines overlayed on the waveform and image segment the screen into first, second, and third leg regions, while distance calculators help confirm the position of a reflector. Those distances are typically presented as follows:

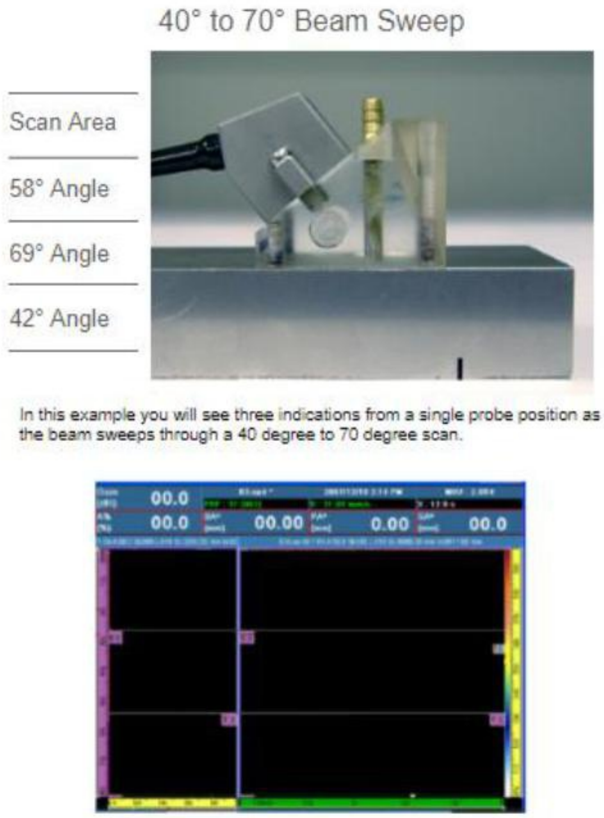
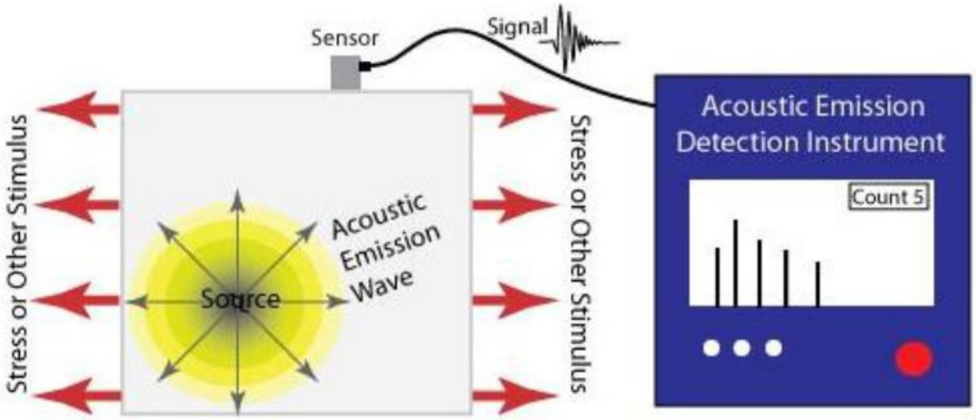


FIG: Three indications from a single probe position as the beam sweeps through a 40 degree to 70 degree scan.

UNIT – V

ADVANCED NDE TECHNIQUES-II

Introduction to Acoustic Emission Testing:



Acoustic Emission (AE) refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material. When a structure is subjected to an external stimulus (change in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors. With the right equipment and setup, motions on the order of picometers (10 -12 m) can be identified. Sources of AE vary from natural events like earthquakes and rockbursts to the initiation and growth of cracks, slip and dislocation movements, melting, twinning, and phase transformations in metals. In composites, matrix cracking and fiber breakage and debonding contribute to acoustic emissions. AE's have also been measured and recorded in polymers, wood, and concrete, among other materials.

Detection and analysis of AE signals can supply valuable information regarding the origin and importance of a discontinuity in a material. Because of the versatility of Acoustic Emission Testing (AET), it has many industrial applications (e.g. assessing structural integrity, detecting flaws, testing for leaks, or monitoring weld quality) and is used extensively as a research tool.

Acoustic Emission is unlike most other non destructive testing (NDT) techniques in two regards. The first difference pertains to the origin of the signal. Instead of supplying energy to the object under examination, AET simply listens for the energy released by the object. AE tests are often performed on structures while in operation, as this provides adequate loading for propagating defects and triggering acoustic emissions.

The second difference is that AET deals with dynamic processes, or changes, in a material. This is particularly