side wall fusion in a weld 20 mm thick. Figure 7-69a shows the prepared edges before welding. Figure 7-69b shows the completed weld, with dotted lines to show the original prepared edges. In Figure 7-69c, a 60° angled shear wave transducer is shown positioned to obtain a maximum echo from the side wall discontinuity. The angle has been chosen to ensure that the beam meets the original prepared face at 90° for maximum sensitivity. Figure 7-69d is a plan view of the same set-up, showing that the center line of the weld has been marked as a reference for measurements. Figure 7-69e shows the trace as the echo maximizes.

The practitioner, once satisfied that the echo is maximized, then makes two measurements; one from the time base, the other on the scanning surface using a ruler. The first measurement is the time base range giving the beam path length to the discontinuity. The second measurement is the horizontal distance from the beam index to the weld center line. These two measurements, together with knowledge of the beam angle, are enough to accurately plot the position of the reflecting point.

Figure 7-69f shows the process for plotting this position. A scale drawing of the weld is made. The center line of the weld is drawn and another perpendicular line through the parent metal at the measured horizontal distance from the weld center line. From the intersection of this perpendicular with the scanning surface, a beam path line is drawn at 60° to the perpendicular to meet the bottom surface. A reflection line from this intersection is then drawn up toward the top surface. The position of the discontinuity is plotted by measuring along the beam path line a distance equal to the measured time base range. The position is marked on the scale drawing ("X" in Figure 7-69f). In practice, dedicated plotting aids are used to make the process easier.

Rod and Pipe Techniques

Figure 7-70 shows an angle beam transducer placed on the circumference of a metal bar in order to detect longitudinal discontinuities along the outer diameter (OD). The beam

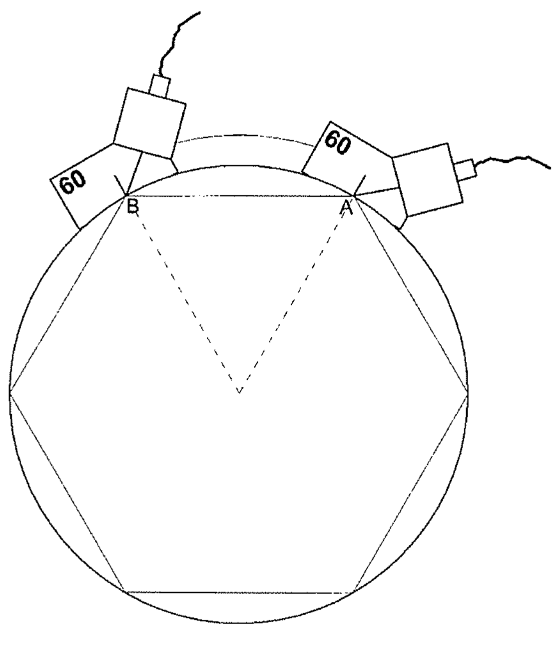


FIGURE 7-70 Angle beam on solid bar.

path length at which an echo from such a discontinuity will appear on the timebase can be calculated from

$$\text{beam path} = OD \times \cos\theta$$

where θ = probe angle.

If the time base is calibrated to a suitable range, the entire circumference can be examined by scanning from A to B in Figure 7-70.

A similar set up is shown in Figure 7-71a, but this time the probe is placed on a pipe. The angle at which the beam strikes the bore of the pipe depends on the transducer angle and the ratio of the inside diameter (ID) to the OD. The beam path length A–B to the ID can be calculated from

$$\text{beam path} = \frac{t}{\cos\theta}$$

where
t = pipe wall thickness
θ = probe angle

When inspecting pipe for OD or ID surface breaking discontinuities it is often easier to calibrate the time base using a reference block similar to the one shown in Figure 7-71b; the drilled hole provides both ID and OD reflecting points. If the pipe wall is very thick, the beam center never reaches the bore of the pipe. This is illustrated in Figure 7-72.

For any given beam angle the maximum wall thickness for a given pipe OD can be calculated from

$$t = \frac{OD \times (1 - \sin\theta)}{2}$$

where
t = maximum wall thickness
θ = Probe angle

From this equation, it is possible to derive another, which will allow the calculation of optimum probe angle to examine the bore of any given pipe. The equation becomes

$$\sin\theta = 1 - \left(\frac{2t}{OD}\right)$$

For convenience, Table 7-3 gives the maximum wall thickness that can be examined with common standard probe angles for a range of typical pipe diameters.

Multiple Transducer Techniques

Through-Transmission. Ultrasonic tests using through-transmission predate the pulse-echo technique and were used in the initial experimentation procedures. By definition, through-transmission implies that two transducers are placed on opposite sides of a test piece facing each other. Whereas with dual transducers only single-sided access is necessary, through-transmission techniques require access to two sides of a component. The test material is either moved through or rotated within the sound field and scanned. It is a valuable technique when used for velocity measurements and in the characterization of material by comparison with a standard.

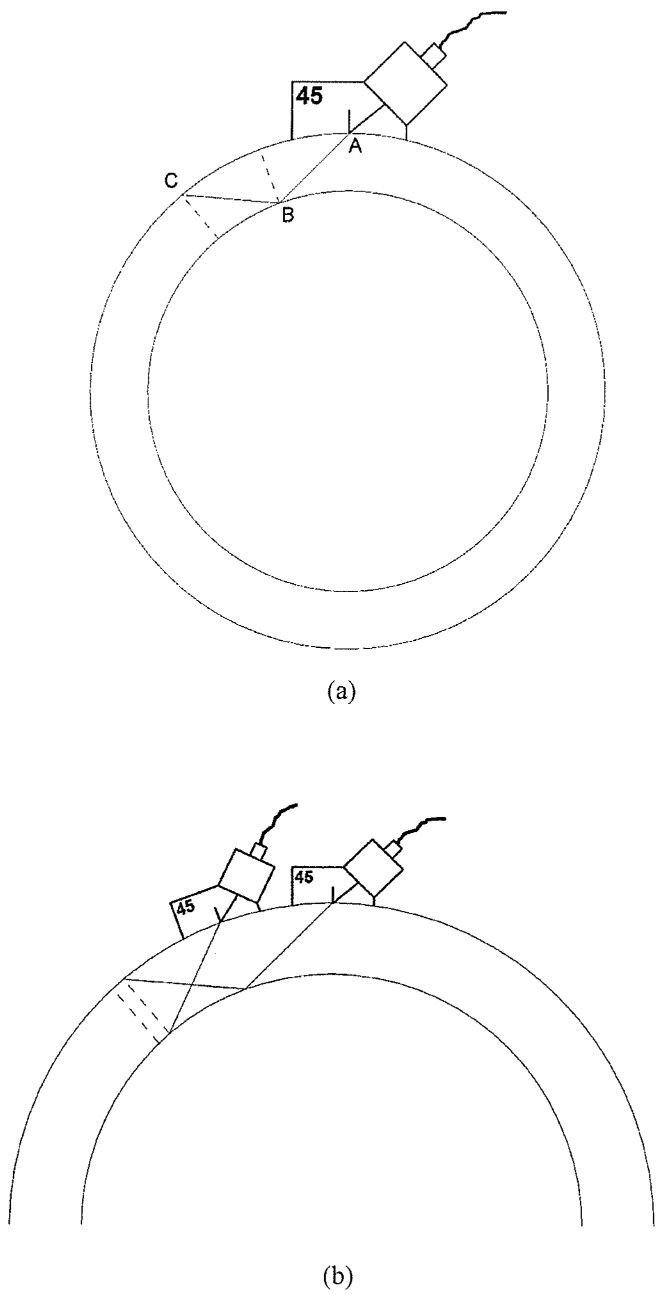


FIGURE 7-71 Single and tandem transducers.

Certain applications lend themselves to this technique. These are usually situations in which the material has high attenuation and pulse-echo techniques are not suitable. Composite material used in the aircraft industry is one example. Other applications include production plate scanning, where banks of transducers are used with water columns (squirters) in the through-transmission mode to inspect for laminations. Other situations exist where discontinuities are close to the surface and can only be detected by observing the loss of transmitted energy.

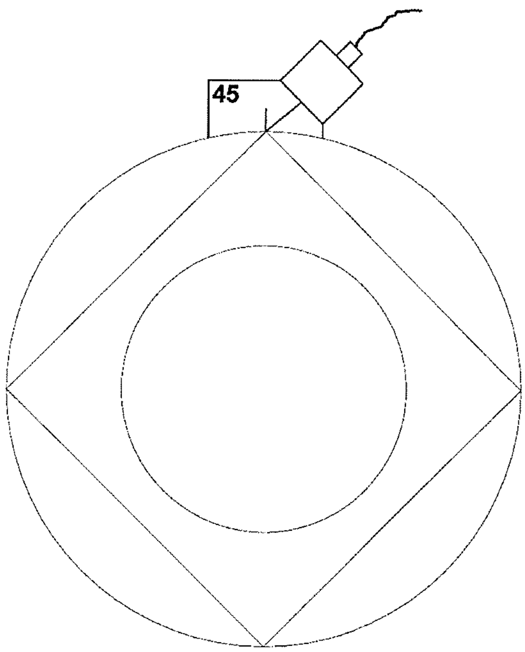


FIGURE 7-72 Angle beam on hollow bar.

Advantages of through-transmission are:

1. Discontinuities in highly attenuative materials may be detected by noting a reduction in the received energy.
2. The complete section can be tested. There are no initial pulse constraints.

The disadvantages are numerous. Through-transmission testing relies on energy reduction as it is "shadowed by" a material discontinuity. Energy reduction can be caused by factors other than the anomalies sought. The possibilities are:

1. Loss of couplant on either side
2. Misalignment of transducers
3. Change in material attenuation
4. There is no positive indication of a reflector and therefore discontinuity depth information is not possible.
5. Variations in surface finish (roughness)

TABLE 7-3 Approximate Maximum Wall Thickness

Pipe OD, inch (mm)	Probe angle 35°	Probe angle 45°	Probe angle 60°
4″ (100)	0.825″ (21)	0.57″ (14.5)	0.250″ (6.5)
6″ (150)	1.26″ (32)	0.87″ (22)	0.375″ (10)
8″ (200)	1.67″ (42)	1.14″ (29)	0.5″ (13)
10″ (250)	2.1″ (53)	1.44″ (36.5)	0.65″ (16.5)
12″ (300)	2.5″ (64)	1.75″ (44)	0.8″ (20)

Tandem Techniques. These are common terms for techniques using two or more transducers arranged so that reflections of the transmitted pulse are detected by a receiver (or receivers) positioned at their predicted exit points. As an example, Figure 7-73a shows a vertical discontinuity that does not break either the top or bottom surface of a metal plate. Such a discontinuity will not reflect sound back to the transmission point. This means that a single angle beam transducer cannot be used. Instead, the arrangement of two probes, one to transmit and one to receive, is used, as can be noted in Figure 7-73b. This is known as the "tandem" technique.

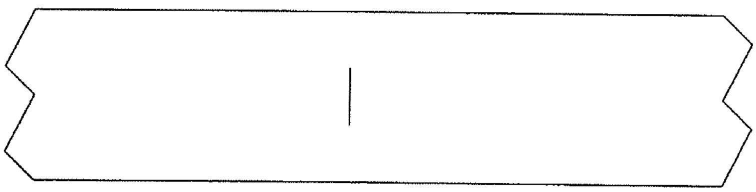
The distance A–B between the probes is dependent on the aiming point of the transmitter. The illustration shows an aiming point in the middle of the plate. If the aiming point were to be nearer the top surface, then the probes would need to be further apart. If the aiming point were to be lower, then the probes would have to be closer together.

Lamb Wave Techniques

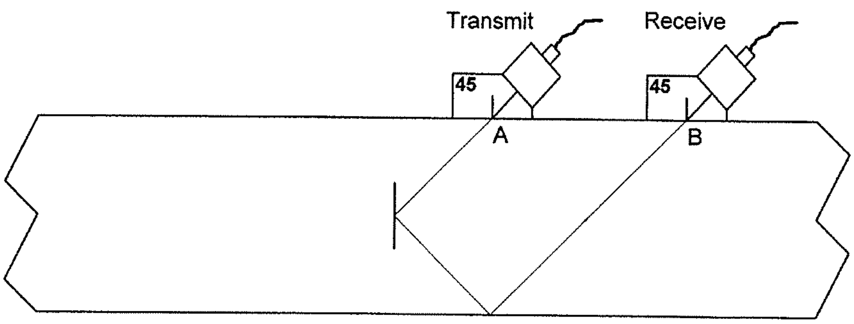
Lamb waves, like Rayleigh waves, propagate parallel to the test surface and have a particle motion that is elliptical. They occur when the thickness of the test material is only a few wavelengths at the test frequency and where the test piece is of uniform thickness. In other words, they can exist best in plate, tube, and wire.

The Lamb wave affects the entire thickness of the test material in such a way that it flexes. Figure 7-74 illustrates a type of Lamb wave where the crests of the wave on the near and far surfaces coincide. These are called symmetrical Lamb waves. Figure 7-75 shows another type of Lamb wave where the crest on one side coincides with a trough on the other. These are called asymmetrical Lamb waves.

These waves are generated at incident angles that depend on the test frequency and material thickness. These parameters also determine the number of modes of Lamb wave that can exist in the test material. In order to generate a Lamb wave, the velocity at which



(a)



(b)

FIGURE 7-73 Tandem transducers on plate.

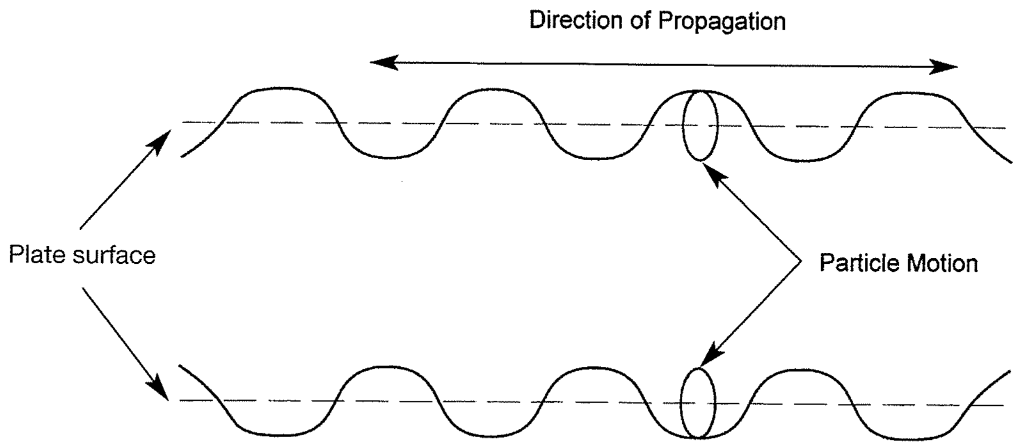


FIGURE 7-74 Lamb wave, symmetrical.

the incident compression wave in the Perspex (Plexiglas) sweeps along the interface must coincide with the velocity of the Lamb wave in the material. This is achieved by adjusting the angle of incidence $i°$. This velocity can be calculated from

$$V = \frac{V_c}{\sin i°}$$

where
V = the velocity of the incident wave front along the test surface
V_c = the incident compression wave velocity in Perspex (Plexiglas)
$i°$ = the angle of incidence in the Perspex

Figure 7-76 illustrates the above formula.

Techniques using Lamb waves usually involve transmit and receive probes facing each other on the test surface. Lamb waves can travel several meters in steel, so they can be used for rapid scanning of plate, tube and, wire.

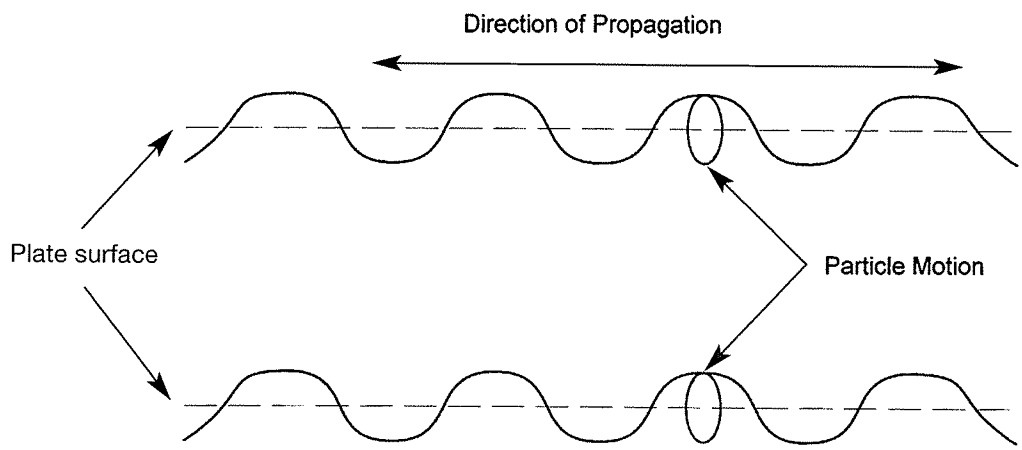


FIGURE 7-75 Lamb wave, asymmetrical.

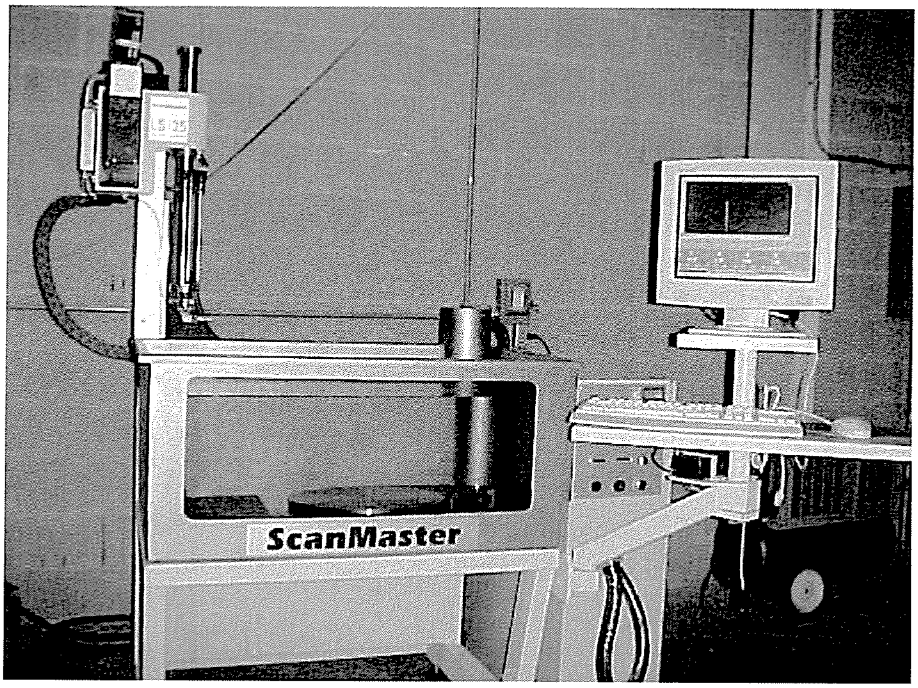


FIGURE 7-76 Multipurpose immersion system.

Immersion Techniques
Contact scanning techniques are mostly used for scanning small areas of components for in-service inspections and for scanning large components that cannot be moved to an immersion set-up. Immersion techniques are far quicker and more convenient for scanning large areas of plates, pipes, and wrought products during manufacture. The techniques lend themselves to automated scanning and recording systems (see Figure 7-76).

There are several advantages of automated immersion testing over manual scanning techniques. These include:

1. Consistent coupling conditions and scanning capability
2. Variable beam angles and beam focusing
3. Interface gating and contour following is possible
4. Improved near-surface resolution and use of higher frequencies

Most contact scanning techniques can be used in immersion testing. In addition, the same transducer can be used for both compression wave and angle beam techniques. To generate any angle of shear wave, the transducer is simply tilted to the appropriate incident angle derived from Snell's law.

Disadvantages include:

1. Setting up is more complicated
2. The part must be compatible with water
3. Air bubble formation interferes with the test

Figure 7-77 illustrates a typical immersion set-up for compression wave scanning. The water path distance (w) is important because there will be multiple echoes from the top surface of the part (entry surface). The spacing between these multiple echoes must be longer than the time taken by the transmitted sound to travel the back wall and re-

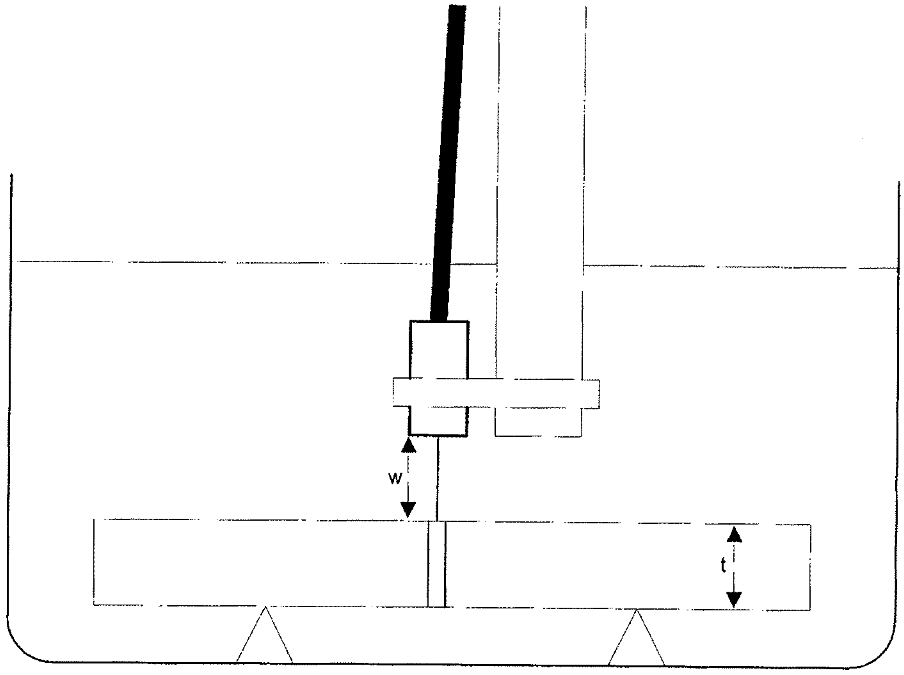


FIGURE 7-77 Immersion technique.

turn. As a rough guide, for steel and aluminum the minimum water path should be about one-quarter of the material thickness. Since sound in water travels at about a quarter of the speed it does in those metals, the back reflection (back wall echo) will appear just before the water multiple. Figure 7-78 shows a typical trace for the above immersion set-up. In this trace, no delay has been used. By using the delay control to get rid of the water path, and calibrating the time base for a suitable range, the trace shown in Figure 7-79 can be obtained.

This trace can be compared to that shown in Figure 7-64b in the contact scanning techniques above. Note that the entry surface echo in Figure 7-79 occupies less space than the initial pulse shown in Figure 7-64b and therefore offers better near-surface resolution.

Figure 7-80 shows the same transducer tilted to an angle of incidence to generate a shear wave beam at 45° to the normal. It can be seen that other refracted angles can be generated by simply changing the incident angle.

Normalization

Normalization is the name given to the process of ensuring that the transducer is actually perpendicular to the entry surface before any other calibration procedure is commenced. The name given to the probe holder in immersion testing systems is the "manipulator." The manipulator allows rotation of the probe in two directions perpendicular to one another. During the initial set-up for an immersion test, the entry surface signal is maximized by careful manipulation of the probe in each axis. As the entry surface echo maximizes in an axis, the rotation is stopped in that axis. When a maximum response has been achieved in both axes, the probe is perpendicular to the entry surface and the transducer has been "normalized."

The normalized position would be used for the compression wave techniques and as a starting point from which to set the incident angle for shear wave techniques.

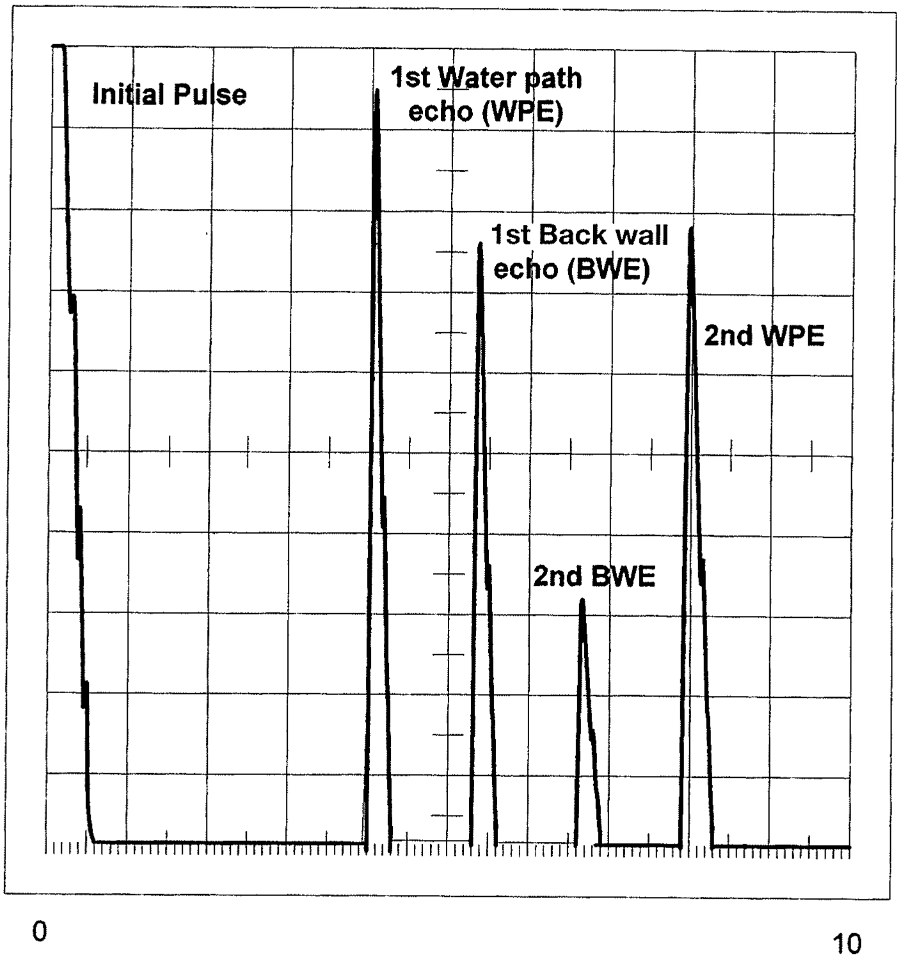


FIGURE 7-78 A-scan of immersion technique.

Interface Triggering (Gating)

Interface triggering or "gating" is often used when the entry surface, because of the component geometry, is not at a fixed distance from the probe face. For example, the stepped surface shown in Figure 7-81 presents three different water path distances (surfaces A, B, and C). Interface triggering starts the sweep as the first entry signal arrives. It acts as an automatic delay control that always ensures that zero on the trace represents the entry surface of the test piece regardless of water path. This is particularly useful, for example, if a round component is being scanned with a spiral scan pattern as the component is rotated past the scanning head. If the component is not truly round, or is being rotated eccentrically, without interface triggering, the whole signal pattern would be moving left and right. Interpretation of the trace visually or automatically under those circumstances would be difficult.

Offset Method for Generating Shear Waves

When carrying out immersion testing of tubular components for longitudinal discontinuities such as the one shown in Figure 7-82, it is not necessary to tilt the probe in order to generate shear waves of a given angle. The appropriate angle of incidence can be

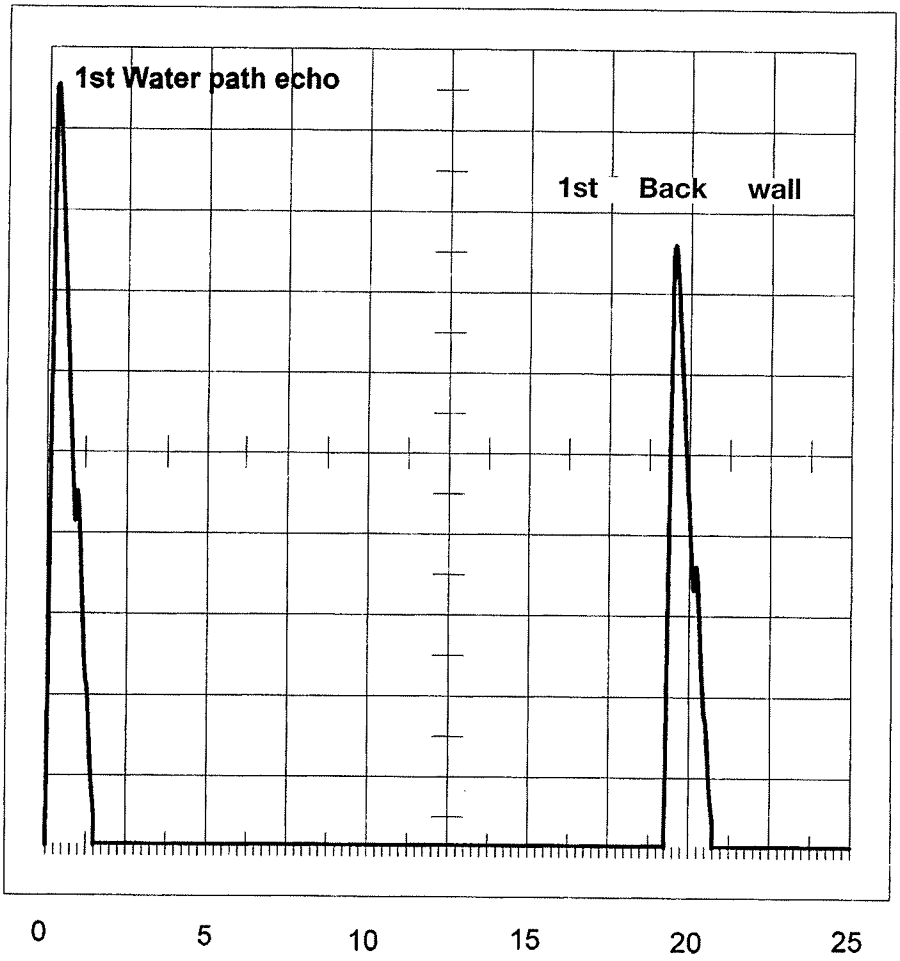


FIGURE 7-79 Delayed immersion A-scan.

achieved by offsetting the probe from the center line by an appropriate amount. The amount of offset for a given required incident angle can be calculated using the following equation:

$$offset = \frac{D}{2} \times \sin i°$$

where
D = component OD
$i°$ = required angle of incidence

Example. Calculate the offset required to generate a 45° shear wave in a 50 mm diameter steel rod. Given that the shear wave velocity in steel is 3240 m/sec, and the velocity of sound in water is 1480 m/sec, from Snell's law, the required angle of incidence is

$$\sin i° = \frac{1480 \times \sin 45°}{3240}$$

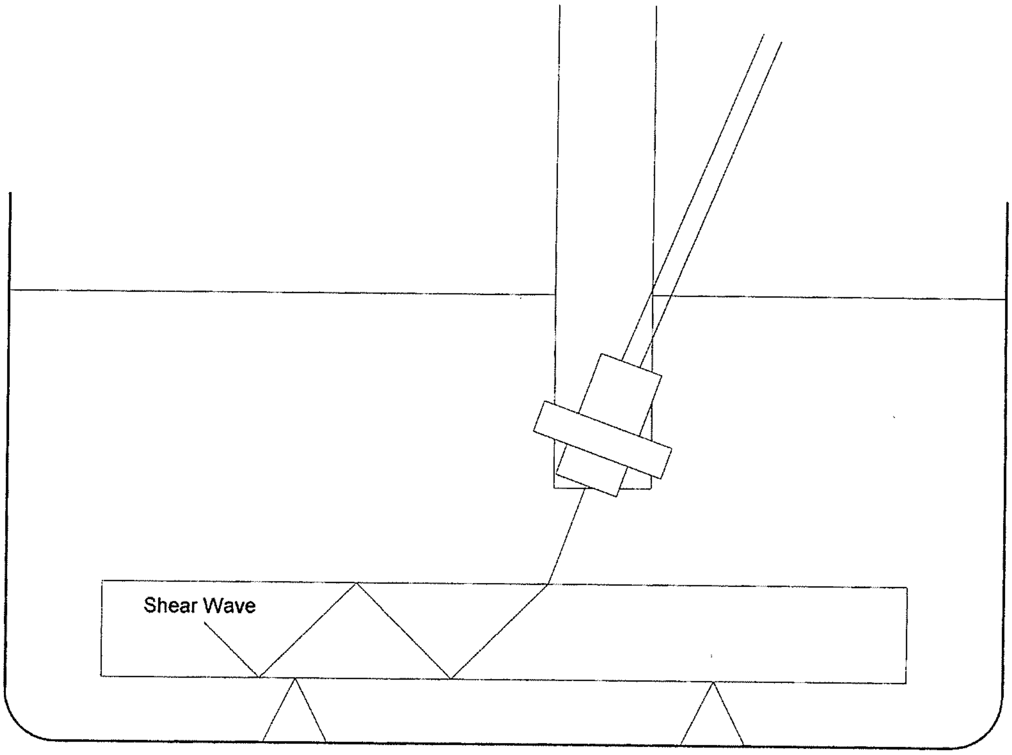


FIGURE 7-80 Angle beam immersion technique.

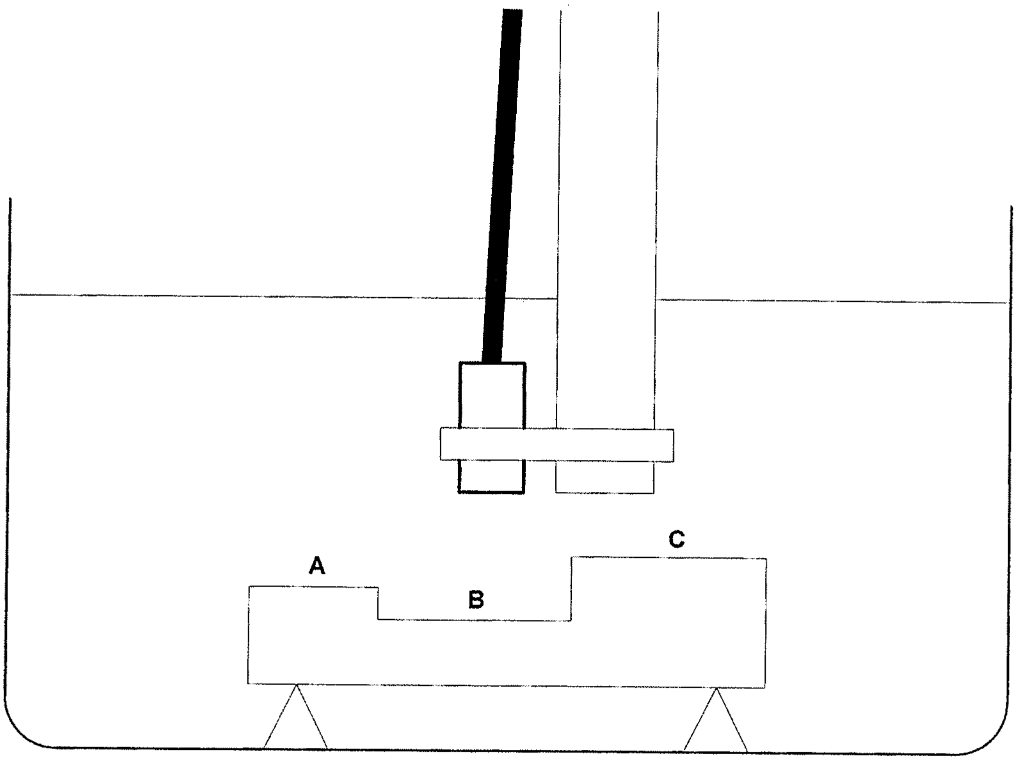


FIGURE 7-81 Contoured component.

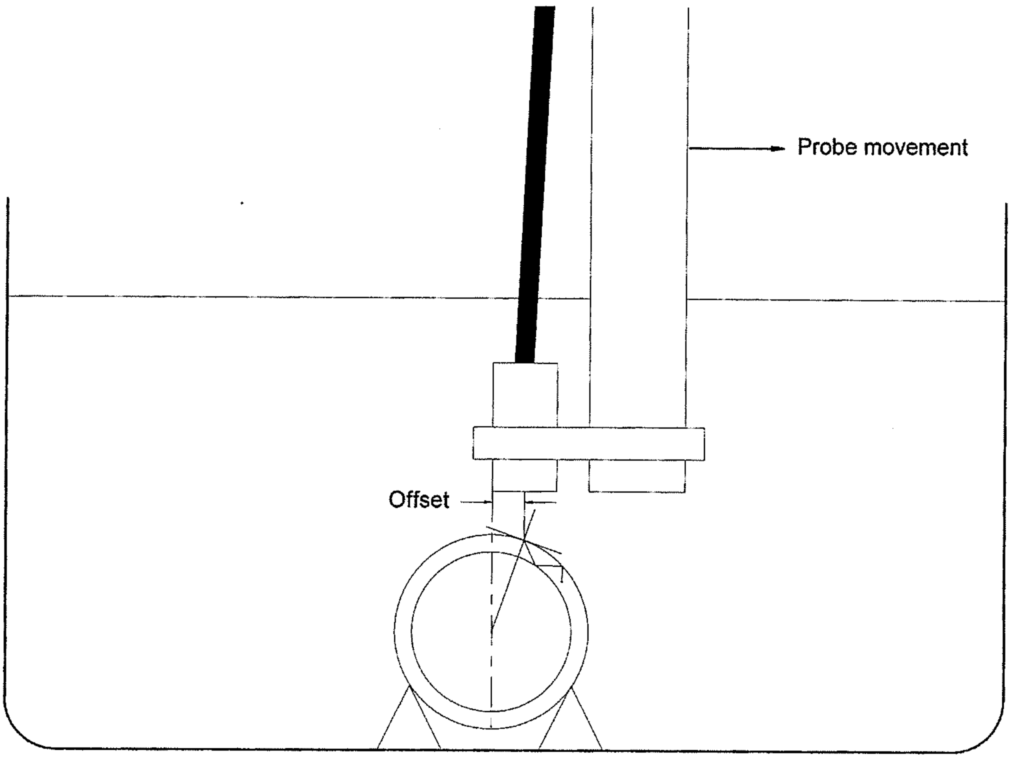


FIGURE 7-82 Offset transducer.

$$\sin i° = 0.3230$$

$$i° = 18.84°$$

Putting the calculated angle into the formula

$$offset = \frac{D}{2} \times \sin i°$$

$$offset = \frac{50}{2} \times \sin 18.84°$$

$$offset = 25 \times 0.3229$$

$$offset = 8.03 \text{ mm}$$

Discontinuity Sizing Techniques

The operating procedure for carrying out the inspection of a specific component must include instructions for setting test parameters that will ensure detection of a given minimum reflector. This can mean that discontinuities will be detected that do not render the component unfit for service. Each discontinuity detected must, therefore, be evaluated against the applicable inspection code or standard. In most cases, the acceptance criteria are set in terms of the length or vertical extent of the discontinuity. In order to correctly evaluate the results, it will be necessary to derive these critical dimensions from the ultrasonic information. Techniques for doing this are known as "sizing techniques."

The techniques available to the practitioner for assessing the severity of discontinuities fall into two categories. First, there are those procedures that quickly "screen" the echo on the trace with reference to an amplitude standard. Examples are the area/amplitude reference standards, the DAC curves, and the DGS curves. In most codes, if the signal exceeds a given proportion of the reference amplitude, the code calls for further investigation (see DAC, page 7.63).

The second category is those procedures that attempt to measure or plot the through-thickness dimension and length of the discontinuity. The techniques include intensity drop, maximum amplitude, and time of flight diffraction (TOFD).

Intensity Drop Technique. The intensity drop technique uses the beam spread to determine the edges of the reflector. Figure 7-83 shows a 20 dB beam spread diagram on a card to which a transparent cursor has been fitted. The cursor has a horizontal line scribed to coincide with the horizontal scale on the card, and it also represents the scanning surface of the component. A vertical line is scribed to denote the reference point (e.g., weld center line). In this example, a weld is being examined and the weld profile has been drawn in wax pencil on the cursor. Note that a mirror image of the weld has also been drawn to allow full skip ranges to be plotted.

Sizing Procedure—Through-Thickness Dimension

Figure 7-84 shows the plan view of a weld with the transducer at a position where a maximum echo height has been obtained from a discontinuity. At this point, the echo height is adjusted to the reference level (i.e., 80%) and the horizontal distance (HD1) measured from the probe index to the weld center line. The corresponding time base range (TB1) is also noted.

The transducer is scanned forward until the signal drops to the intensity drop wax pencil line. At this position, the bottom edge of the plotted beam will be reaching the top of the discontinuity. The new horizontal distance (HD2) and timebase range (TB2) are recorded.

Last, the transducer is scanned backward, through the maximum again and back until

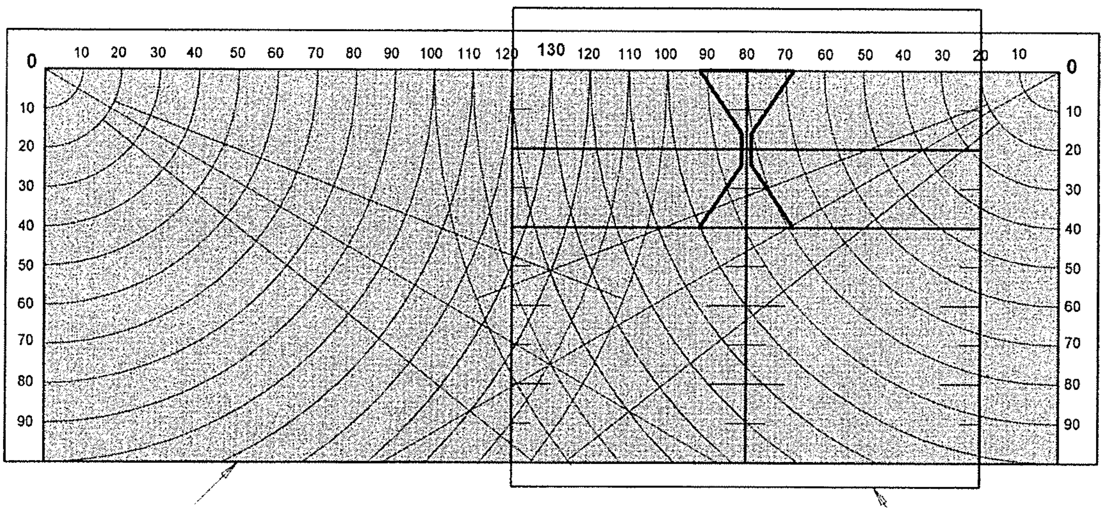


FIGURE 7-83 Beam plot card.

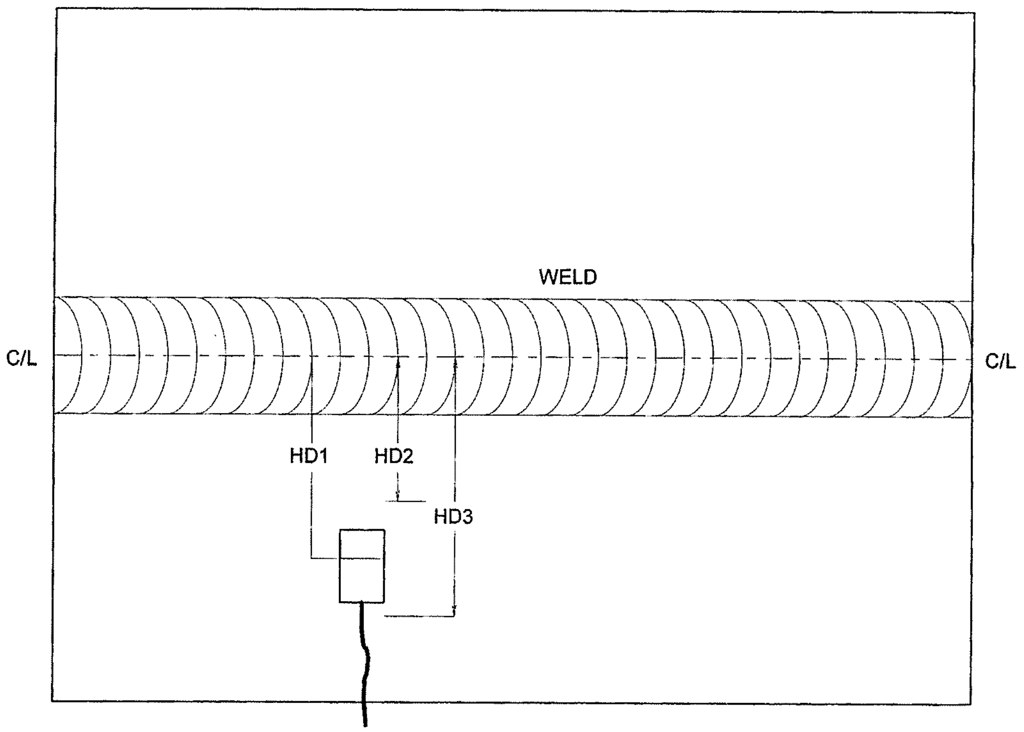


FIGURE 7-84 Weld center line.

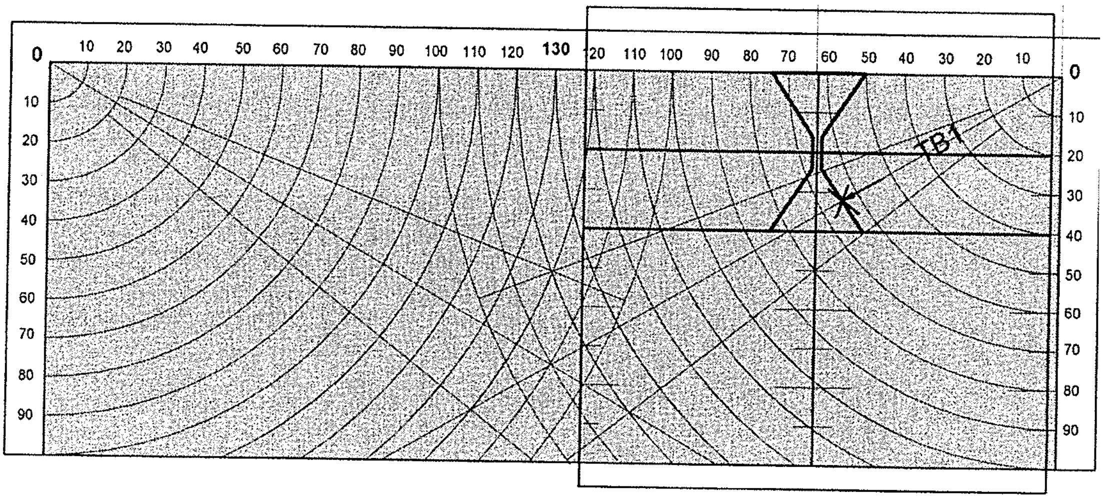
the signal again drops to the wax pencil line at HD3. The distance and range (TB3) are recorded. This position represents the top edge of the beam just striking the bottom of the discontinuity.

There are now three sets of data for the through-thickness dimension of the reflector. These are the probe position (HD) and time base range (TB) for top, middle, and bottom of the discontinuity. These data are now transferred to the cursor of the plotting aid.

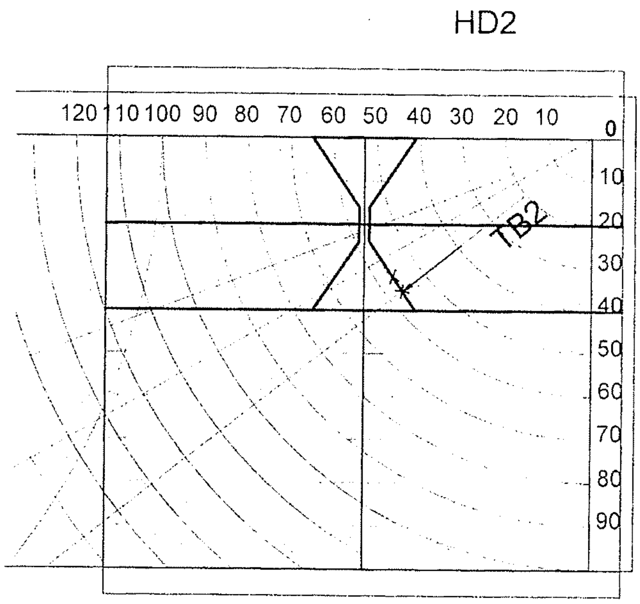
Figures 7-85a, b, and c show the steps for plotting the discontinuity. In Figure 7-85a, the cursor has been set with the weld center line positioned at a distance HD1 on the card's horizontal scale. Going down the beam path scale, a cross has been marked with a grease pencil at the time base range for the middle of the discontinuity (TB1). Note that in this case the distance TB1 has put the cross in the mirror image on the cursor. This means that the reflection has come from beyond the half-skip position when the beam is on its way up to the full-skip position. Because the weld profile has been sketched onto the cursor it is immediately obvious that this discontinuity is close to the weld side wall.

In Figure 7-85b, the cursor is shown to be repositioned at HD2 and a new cross marked at range TB2. Note that this cross is marked where the bottom edge of the beam on the beam spread diagram intersects with the beam path scale. The new cross marks the top of the discontinuity. Note that it also lies near to the side wall.

The bottom of the discontinuity is plotted as shown in Figure 7-85c. The distance HD3 and range TB3 place a cross where the top edge of the beam intersects the beam path scale. Again, the cross falls close to the side wall. The three crosses can now be joined to show the extent of the discontinuity in the cross-section of the weld. This can be measured and evaluated against the relevant acceptance standard.



(a)



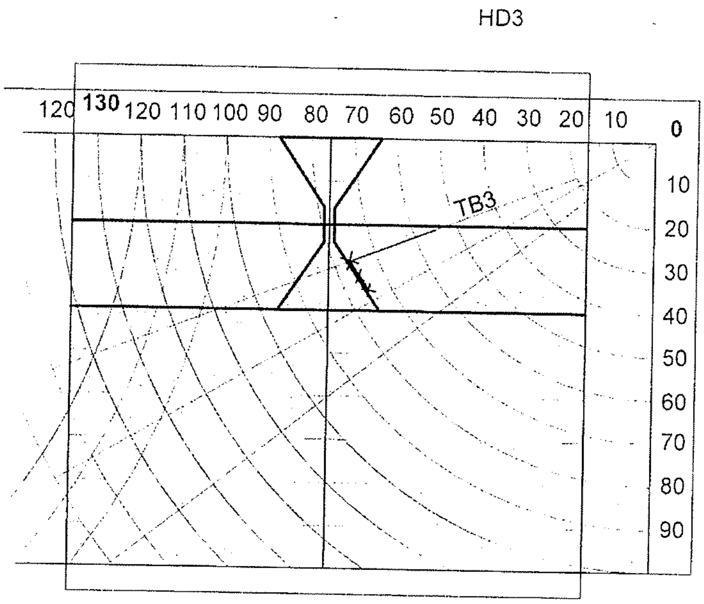
(b)

FIGURE 7-85 Plotting the discontinuity.

Sizing Procedure—Discontinuity Length

Using the intensity drop method to measure the length of the discontinuity is much simpler than the procedure for the through-thickness dimension. All the measurements and marks are made on the test surface. Figure 7-86 shows the transducer positions for the measurement.

Position 1 is where the transducer detects a maximum echo. The position is marked



(c)

FIGURE 7-85 *Continued.*

with grease pencil. The transducer is scanned sideways until the echo has dropped by 6 dB and the position marked on the surface (position 2). The transducer is then scanned through position 1 and on to position 3, where the signal has again dropped by 6 dB. Position 3 is marked on the surface. The distance "L" between positions 2 and 3 is the length of the discontinuity. Care should be taken to ensure that the –6 dB point is the "end" of the discontinuity.

Maximum Amplitude System

The maximum amplitude system (MAS) uses the same plotting aid as the intensity drop system. However, with MAS only the beam center is used to plot the extent of the discontinuity. The method is particularly suitable for sizing discontinuities that are multifaceted, such as cracks or slag inclusions. Figure 7-87 shows an angle beam transducer aimed at an internal crack-like target.

Across the beam, various facets of the target are oriented perpendicular to that part of the beam. The result is that several echoes get back to the receiver in a cluster over a short time period. This gives a signal pattern similar to the one shown in Figure 7-88. The signal from each facet of the discontinuity reaches a maximum as the beam center moves onto it. If the transducer is moved, forward or back, from the position on the test surface at which the overall signal pattern is maximized, the signal pattern as a whole decays. So far everything is the same as for the intensity drop method. However, if the dynamic signal pattern is studied in detail during this decay, signals from the individual facets will be seen to rise and maximize as the beam center reaches that area of the discontinuity. As the transducer is scanned right across the discontinuity region, each facet in turn will grow, maximize and decay. Each maximum represents a point on the face of the discontinuity.

The sizing procedure starts in the same way as the procedure for intensity drop—by

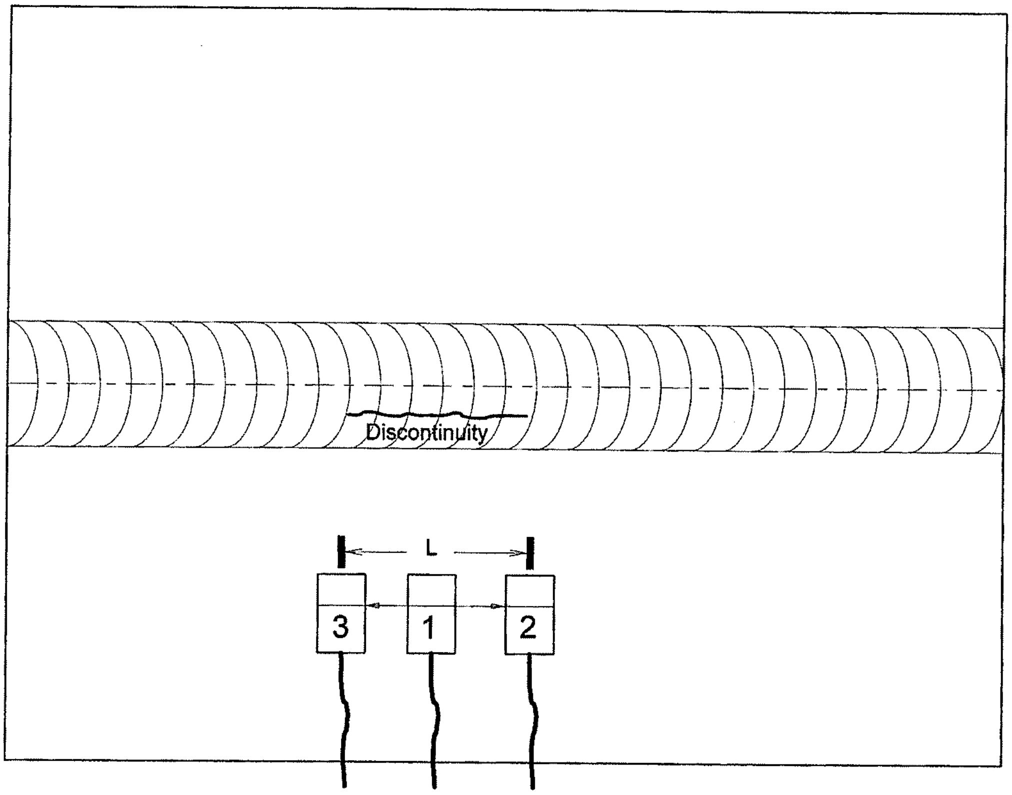


FIGURE 7-86 Plan view of discontinuity.

maximizing the overall signal from the discontinuity. The horizontal distance to the weld center line and the time base range are recorded as before. As the transducer is scanned forward from this position, the signal pattern is scrutinized to detect the rise in signal of a facet echo while the main pattern is falling. As each facet echo maximizes, the HD and TB distances are recorded until the last facet has started to fall and the overall signal is lost.

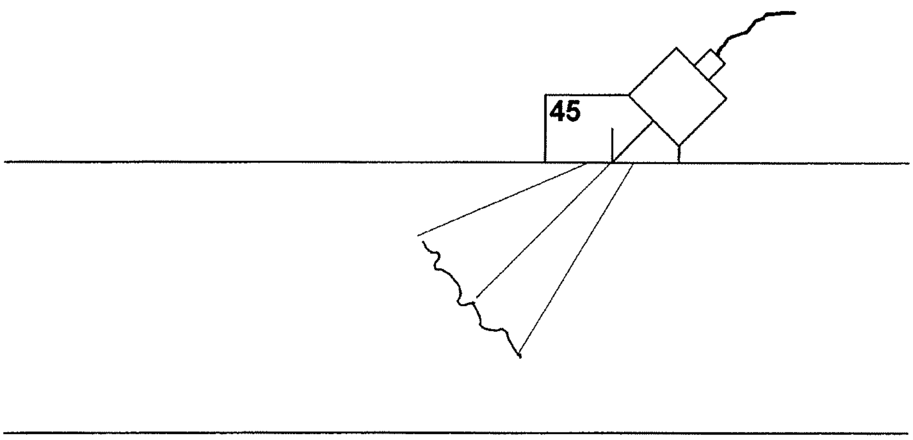


FIGURE 7-87 Sectional view of discontinuity.

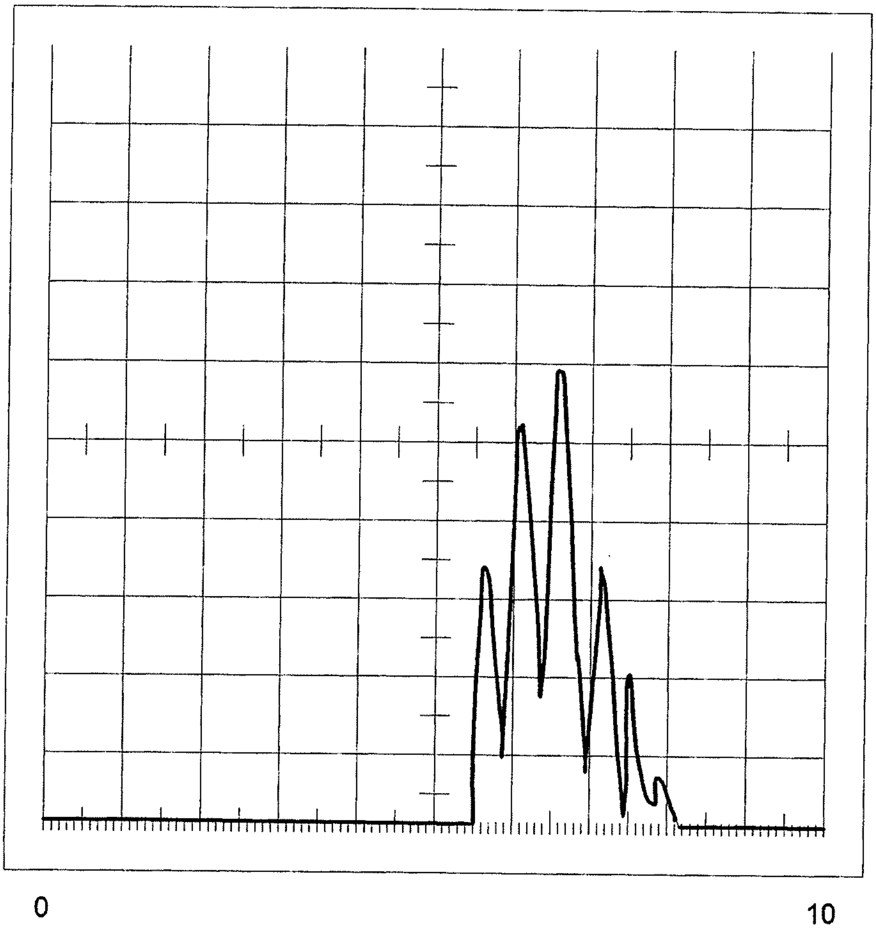


FIGURE 7-88 A-scan of discontinuity.

The process is repeated on the backward scan from the overall maximum position until the last maximum in that direction has been recorded. The coordinates of all the recorded points can then be transferred to the cursor of the plotting aid.

The set-up for the plotter is the same as that shown in Figure 7-83, except that only the beam path scale is used to plot the points. There will be more points to plot for each discontinuity than for the intensity drop method. Joining these points on the cursor traces the shape and plane of the discontinuity after the fashion of "connect the dots" picture books for children.

During the scanning procedure, as each maximum is being detected, the gain can be increased to bring in the weaker signals from the smallest facets. If this is done, the last maximum detected is likely to be a tip diffraction signal from the end of the discontinuity. This signal was described by Sproule to be –30 dB below the amplitude of a corner reflector at the same depth. In practice, this can be difficult to identify, but if it does appear, it very accurately pinpoints the extremes of the discontinuity.

Tip Diffraction Techniques

The tip diffraction techniques follow on from the "last maximum" in the maximum amplitude technique. If the extremities of the discontinuity can be accurately plotted, it follows that the discontinuity can be "sized." Since the diffraction signal originates at a "tip," it would appear to be an ideal feature to exploit. There are two basic approaches to tip diffraction sizing:

1. Using a standard angle beam transducer to carry out an additional scan specifically to size discontinuities that have already been detected
2. Using the time of flight diffraction (TOFD) technique in which two angled compression wave transducers are used to both detect and size in one pass

Using a Standard Angle Beam Transducer. When a beam of sound strikes the tip of a reflector, the reflected energy "diffracts" at the tip to form a spherical wave, as shown in Figure 7-89. The spherical wave will eventually reach a large part of the component surface. This means that the diffracted energy can be detected over a much larger area than the main beam, which is very directional. The diffraction energy is greatest as the beam center encounters the tip. The energy as this point is reached is typically 30 dB less (i.e., –30 dB) than a corner reflector at the same depth.

This means that the tip diffraction signal is weak and may only be two or three times the noise level (i.e., the signal to noise ratio is typically around 2:1–3:1). These small signals can be difficult to identify on the screen. Nevertheless, the signal can frequently be identified, and in these cases it becomes a useful sizing tool.

The procedure is similar to the maximum amplitude method. Once the discontinuity has been identified and positioned within the component, the transducer is arranged to obtain a corner reflection at a depth close to the discontinuity depth. The signal from the corner reflector is adjusted to a reference height (typically 30% FSH). The gain is then increased by 30 dB (+30 dB) and the transducer moved to the discontinuity region. As the transducer interrogates the discontinuity, the screen is studied for a signal that rises to the reference level as the main echo signal decays. As this signal reaches its maximum, the coordinates are noted and the tip position plotted as before.

It is often considered preferable to use an unrectified (RF) display to carry out tip diffraction techniques. This is because there is a phase reversal between diffraction signals originating at the top tip and those originating at the bottom tip of a discontinuity. With small discontinuities, it is sometimes possible to identify top and bottom of the discontinuity at the same time.

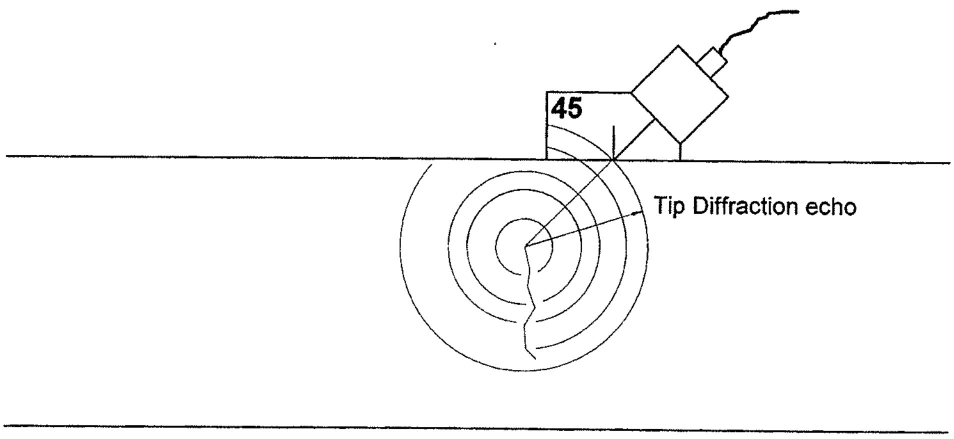


FIGURE 7-89 Tip diffraction echo.

Time of Flight Diffraction (TOFD) Technique. The TOFD technique, first used by M. G. Silk in 1977, uses tip diffraction to identify the top, bottom, and ends of a discontinuity in one pass. Silk chose to use an angled compression wave for the TOFD technique rather than a shear wave, for two reasons. First, the tip diffraction signal is stronger than a shear wave diffraction signal, and second, a lateral wave is produced that can be used to measure the horizontal distance between the transmitter and receiver.

The tip diffraction signal is generated at the tip of the discontinuity—effectively a "point" source. According to Huygens, a point source produces a spherical beam. Figure 7-90 shows both the lateral wave and a diffraction beam from the tip of a reflector.

Figure 7-91 shows a typical TOFD transducer set-up on a component with a vertical discontinuity. There are four sound paths from the transmitter to the receiver. Path "A" is the lateral wave path traveling just below the surface. Path "B" is the tip diffraction path from the top of the discontinuity. Path "C" is the tip diffraction path from the bottom of the discontinuity, and path "D" is the back wall echo path.

Figure 7-92 shows a typical unrectified trace for the four signals. Note that the phase relationships A and C are in opposite phase to B and D. The important difference to note is between B and C—the top and bottom diffraction signals are in opposite phase. This phase difference allows the practitioner to identify those points.

Assuming that the diffracting tip is centered between the two transducers, the depth of the tip below the surface can be calculated from

$$depth = \sqrt{\left(\frac{BPL}{2}\right)^2 - \left(\frac{HD}{2}\right)^2}$$

where

BPL = beam path length for the signal in question
HD = beam path length for the lateral wave

The distance measurements taken from the ultrasonic trace must be made from the same part of each waveform. In the example trace shown in Figure 7-92, the largest half-cycle would be selected. For signals A and C, this is negative, and for signal B, positive. Advances in computer technology have made it possible to carry out all the calculations

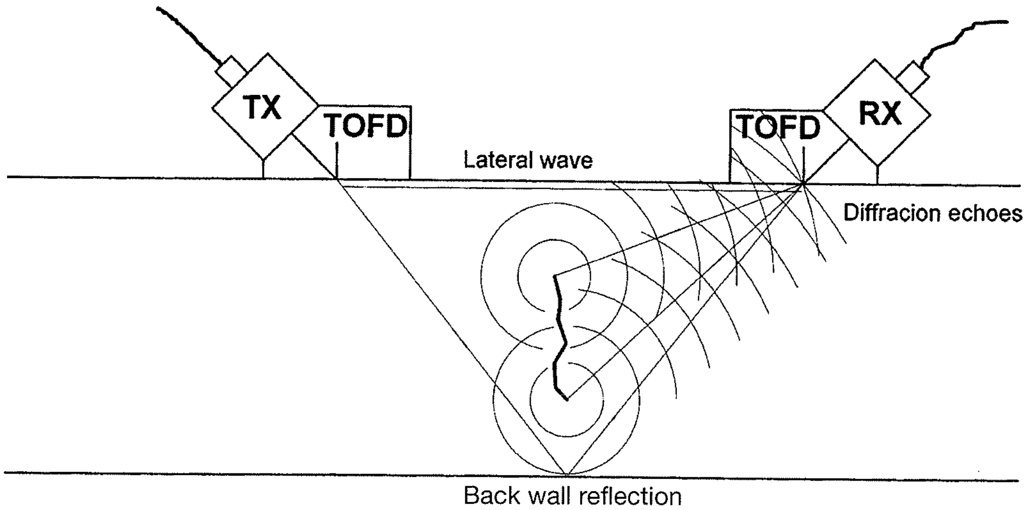


FIGURE 7-90 TOFD.

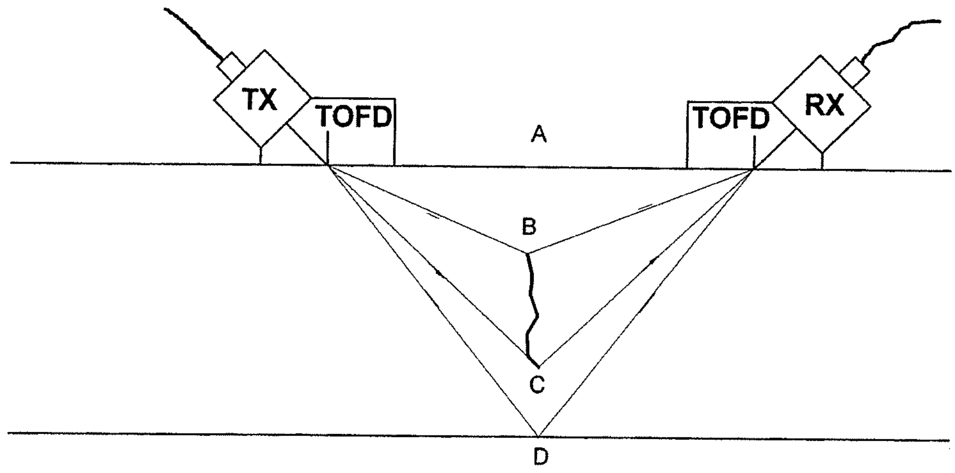


FIGURE 7-91 TOFD.

and for plotting to be handled automatically and stored for subsequent evaluation. The method that has been chosen to display this TOFD data presents the information in a special "B-scan" form that is easy to assimilate. The way in which the positive and negative half cycles are displayed needs explaining.

An echo arriving at the receiver is a pulse of a certain pulse width and amplitude. In conventional B-scan displays, this pulse is displayed as a bright spot whose diameter is proportional to the pulse width and whose brightness is proportional to the signal amplitude. In some ways, it is like a broad pencil tip that can be used to draw pictures in light or bold broad strokes. The pulse is really a short burst of a few cycles of alternating waveform. In the TOFD system, the waveform is depicted in grayscale, with positive half-cycles tending toward white, and negative half-cycles tending toward black (see Figure 7-93). This allows particular half cycles to be identified for measurement purposes, and phase changes to be recognized for determination of top or bottom echo.

Figure 7-93 shows a typical computer screen for a TOFD inspection. The image shows details of the component (in this case, a weld) as well as the TOFD B-scan image and an A-scan trace. In this image, left to right represents the component thickness, and the vertical dimension represents scan length.

The A-scan trace shown corresponds to a slice through the weld at the location indi-

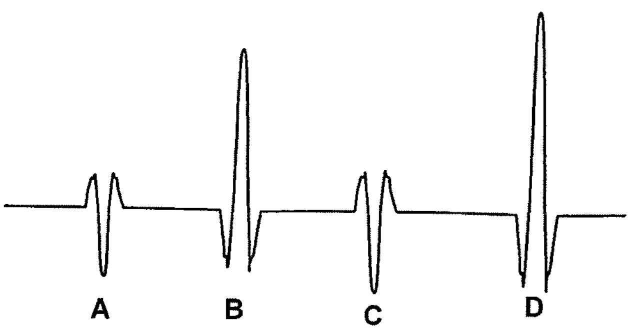


FIGURE 7-92 TOFD RF signals.

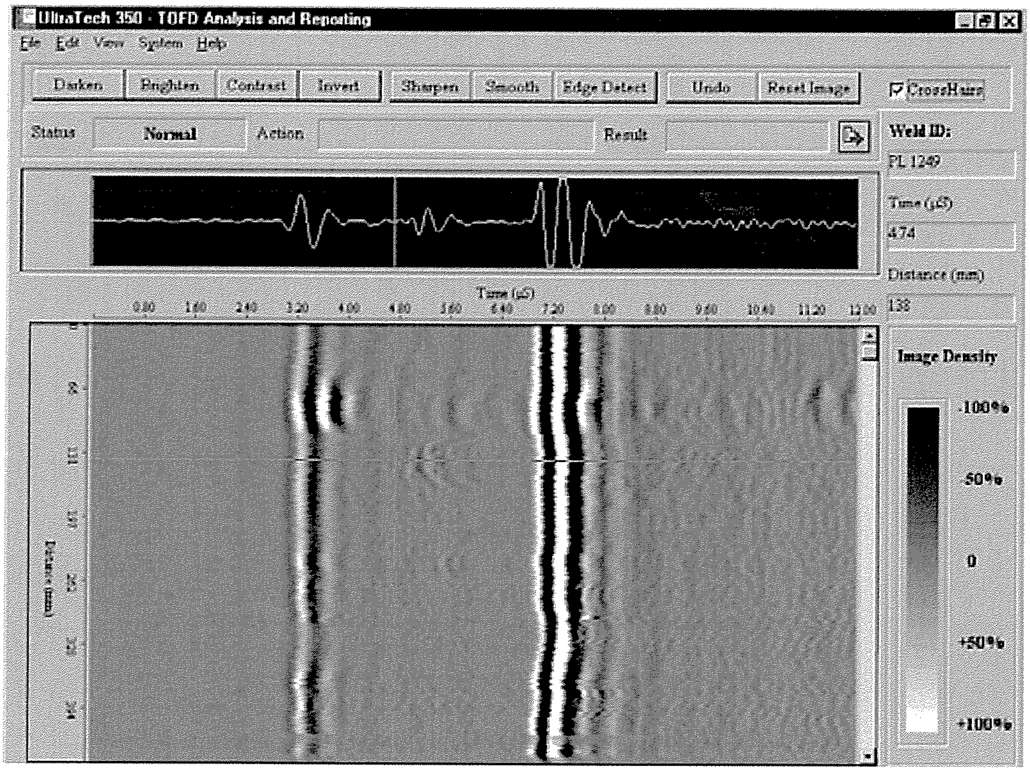


FIGURE 7-93 B-scan presentation of TOFD.

cated by the cross hairs of the cursor. The striped band on the left of the TOFD image represents the lateral wave, and the bold striped band to the right of the image represents the back wall signal. The difference in boldness is due to the different signal amplitudes. Following the horizontal cross hairs and about halfway between the lateral wave and back wall "stripes," a series of faint horseshoe-shaped stripes can be seen. These are diffraction signals from a small discontinuity. The A-scan trace shows the signal clearly.

In this example, the discontinuity has a very small dimension in the through-thickness dimension, but close study of the A-scan shows a small phase shift in the last half-cycle of the discontinuity signal. This tells the practitioner that the distance from top to bottom of the discontinuity is about the same as the pulse length for this particular discontinuity.

A much bolder indication can be seen toward the top of the lateral wave line, suggesting a discontinuity at, or just below, the surface. In Figure 7-94, the cursor has been moved to this location. The lateral wave signal can be seen to be longer and stronger than at the previous location. The fact that the wave shape stays in phase suggests that the diffraction echo, which is extending the signal, has the same phase as the lateral wave. In other words, it is a bottom tip signal. However, it is not possible in this case to see where the lateral wave ends and the bottom tip begins, and so it is not possible to say how deep the discontinuity extends below the surface. The TOFD method is limited in its ability to size near-surface discontinuities when the depth is similar to the pulse length.

The transducers used in these TOFD techniques are angled compression wave transducers (refracted longitudinal wave). The common angles used are 60° and 70°, al-

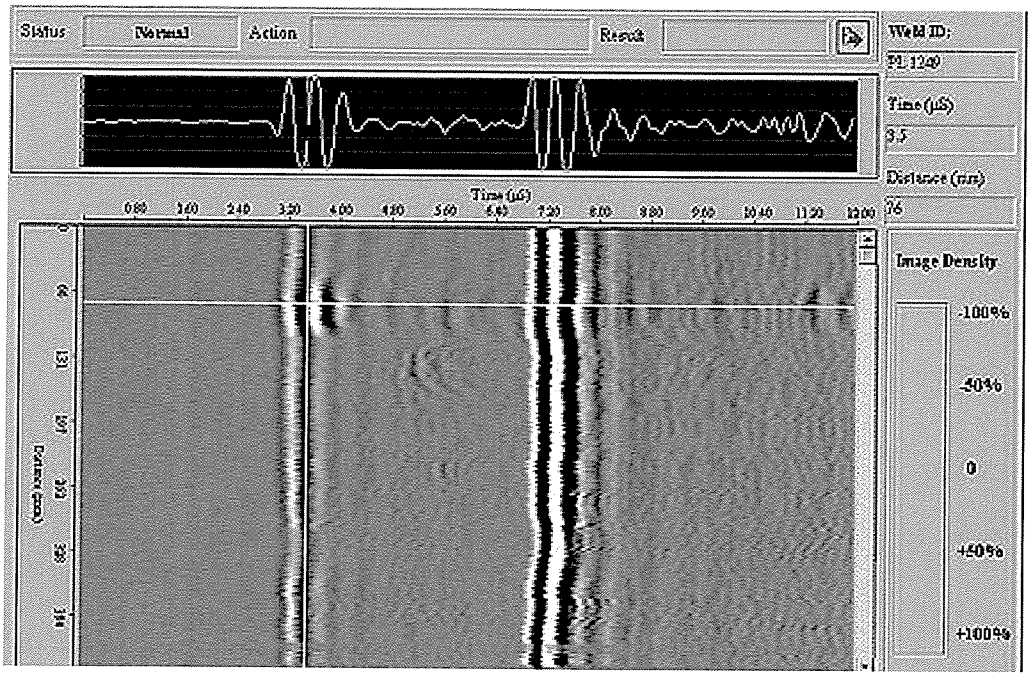


FIGURE 7-94 B-scan presentation of TOFD.

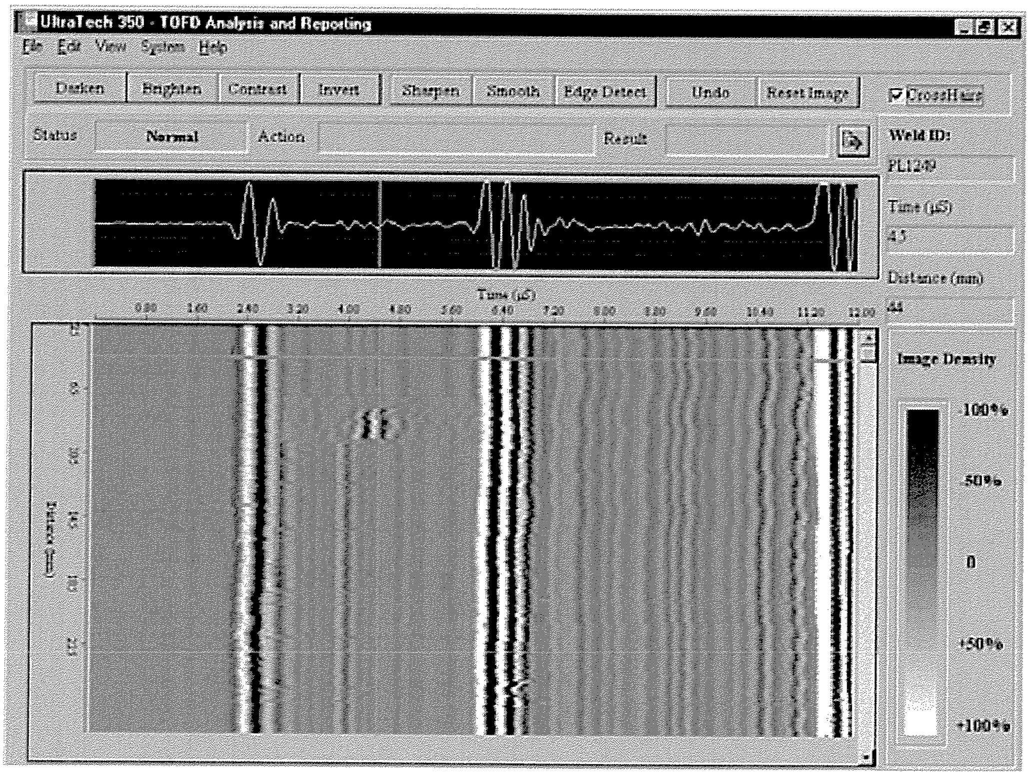


FIGURE 7-95 B-scan presentation of TOFD showing shear wave.

though other angles may be used if the component thickness makes it necessary. The design and construction of the transducer is important in order to promote a good lateral wave. Previous theory has suggested that a shear wave should also exist in the component, and this is true—it does. Figure 7-95 shows a little more of the trace for the above example. On the extreme right of both the A-scan and TOFD B-scan, the shear wave can be seen. Since it arrives well after the other signals, it does not present a problem in this application.

V. VARIABLES

There are a number of variables that can influence an ultrasonic examination. Because of the many different materials tested, the component configurations, and the anomalies that can occur during an ultrasonic inspection, it is impossible to list or predict all of these variables. The following subsections deal with some of the more common variables that may have an affect on the results of a test.

Temperature and Velocity

Temperature is an important factor when considering ultrasonic examination. Temperature affects the velocity of sound in most materials to a greater or lesser degree depending on the material. Water, for instance, undergoes velocity changes with temperature. The velocity of water at 68°F (20°C) is approximately 1480 meters per second, whereas at 86°F (30°C) the velocity is approximately 1570 meters per second. At the other end of the scale, water at approximately 34°F (1°C) is approximately 1414 meters per second. Velocity changes in metals are not as dramatic as with water, but changes do occur. When conducting examinations, consideration should be given to temperature variations between the calibration standard and the component. Some specifications require that the temperature difference of the calibration standard and the component be within 20°F (–7°C). Of greater influence than the component is the temperature in the Plexiglas wedge or delay line. Temperature variations can cause beam angle changes and/or alter the apparent delay on the time base. When conducting examinations at elevated temperatures, special high-temperature transducers and couplants are usually necessary. Calibration blocks need to be heated to a temperature similar to that of the component to be examined prior to calibration, and the transducers should be allowed to warm up to the examination temperature before using them to calibrate the system. Temperature variations will also result in dimensional changes to the part, which must be taken into consideration when calibrating and testing material.

Attenuation

In addition to the change in velocity, temperature can also affect the amount of attenuation in some materials. Apparent changes in attenuation can be indicative of changes in the material structure. Hardened steel, for example, may exhibit less attenuation than its untreated counterpart. Sudden changes that are noted in signal amplitude can yield valuable data about the component being examined (see Hydrogen Embrittlement in Section VII). Microporosity in the material may have the same affect on the apparent attenuation. Material that exhibits high attenuation may require examination using lower test frequencies due to the probable larger grain size.

Frequency and Grain Size

For details regarding this variable, see Scatter in Section II, page 7.26.

Resolution

Pulse length can affect the resolution characteristics of the system. Refer to Resolution, page 7.53.

Surface Conditions

An important variable is that of surface condition. The differences in surface finish can result in large variations in the results of an examination. Paint or other coatings can have similar effects. Tightly adhering coatings on the surface generally allow good transfer of the energy. Loose or flaking coatings are undesirable and should be removed prior to conducting the examination. When calibrating the equipment for reference sensitivity on critical applications, it is essential to evaluate the component for any energy losses due to surface condition and apparent attenuation variations. The procedure for this is fairly simple and is performed by using two transducers in a "pitch–catch" technique. See Transfer Correction Technique in Section IV (page 7.65) for details of this procedure.

Diameter Changes

Changes in the diameter of the test surface can result in changes in test sensitivity. The effective transducer size is limited to its contact area. It is highly desirable to perform the system calibration on a surface with a diameter similar to the one being scanned on the component under test. Compensation for diameter changes should be made by either adding or subtracting gain after calibration, prior to examination of the component.

Contact Pressure and Couplant

The amount of couplant used and the contact pressure on the transducer can create differences in signal amplitude. Too little couplant will leave the surface dry and therefore create an air boundary between the transducer and the component surface. Excessive pressure can squeeze the couplant from under the transducer.

Dendritic Structures

Dendrites are branch-like grains that exist in certain metal structures and can cause problems, particularly in stainless steel welds. These dendrites form in the direction of heat dissipation during the welding process. A single grain can grow from one weld pass to the next, leaving elongated grains that can effectively redirect the sound energy. Indications that are plotted to originate from, e.g., the fusion line may actually originate from the root of the weld if the energy has been redirected. Special procedures including the use of refracted compression wave transducers may be necessary to reduce this effect.

Gain

The use of excessive gain can exaggerate otherwise insignificant indications. This emphasizes the need for precise calibration.

Other Factors

Other factors such as transducer frequency, diameter, and angle can affect the examination results. It is necessary to follow a qualified procedure when carrying out an examination, particularly when repeatability is an issue. Ultrasonic examination requires careful consideration of all the variables. The practitioner needs to be mindful of these variables and others that may present themselves. Attentiveness, awareness, and the ability to recognize anomalies are important.

VI. EVALUATION OF TEST RESULTS

In order that the terminology used in this section be understood, the flow chart in Figure 7-96 should be considered.

When NDT is specified, the following information must be provided:

1. The component description
2. The test method
3. The specification for the test

The specification for the test is most important. If there is no agreed upon definition regarding the type, size, and quantity of discontinuities, meaningful accept/reject determination will not be possible. The specification used should consider the component's "fit-

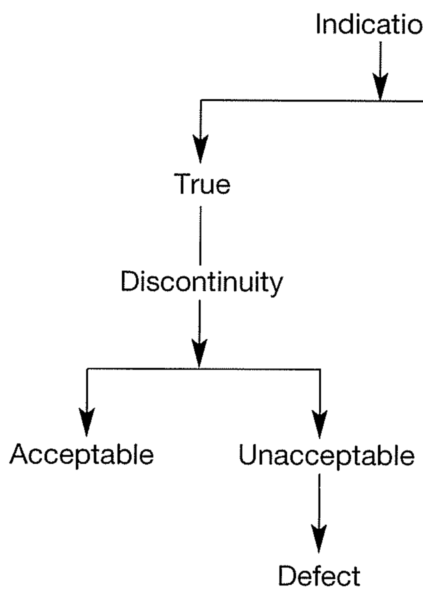


FIGURE 7-96 Procedure flow chart.

ness for purpose." This means that the component should not have any discontinuities that would lead to its failure. This determination should be made by the designer of the specific component, who will use "fracture mechanics" to make this judgment. Evaluation of any indication should be made in consideration of the code or specification referenced in the purchase order or contract.

Reporting

Unless a report is generated at the conclusion of an examination, there will be no record of it having been conducted. Examination repeatability is important, especially where the condition of a component is to be monitored periodically. Test reports should be developed that require certain information. A situation may arise where specific test reports are unavailable and the examiner may have to improvise.

Always ensure that as a minimum the following details are recorded clearly and concisely.

Identification

Date, Time, and Place of examination

Examiner's name and certification level

Component examined and its serial number if applicable

Procedure, specification, or standard to which the test was performed. Note any revision number, changes, or deviations from the procedure.

Equipment

Instrument used, including serial number

Transducers used, including frequency, serial number, and angles

Calibration standards or reference block(s)

Couplant used—include batch number where appropriate

Calibration

Time base (range and units per division)

Calibration sensitivity and DAC curve (if used)

Scanning sensitivity

Reference level for recording

Examination details

Area scanned

Limitations and interferences

Percentage complete coverage

Results

Indications noted—percent DAC (as appropriate), location of indications

Classification of discontinuities (if required)

Scale drawing or plot of indications

Comments—surface condition, temperature, etc

Note. Reports should be concise and accurate. The person reading the report may not be very familiar with UT. A drawing or sketch is easier to follow than a lengthy description.

VII. APPLICATIONS

Product forms commonly subjected to ultrasonic inspection can be wrought, cast, welded, composite, or other materials. There are two main applications for nondestructive testing (NDT) in general. These are production-type tests of either raw materials and/or new components, and inspections that take place at a time when the component is in service. There is virtually an infinite list of areas where ultrasonic testing can be applied. It is, however, prudent to remember that the shape and orientation of a discontinuity does not always lend itself to ultrasonic inspection.

Economic Factors

The application of almost any method of nondestructive testing is dependent on factors such as the nature of the material, accessibility to critical areas, component geometry, discontinuities that are sought, and cost factors. From an economic standpoint, the cost of dismantling a system for NDT plus the cost of the NDT itself has to be considered against the cost of replacement of the component or system. The amount and method of inspection necessary to ensure an acceptable product or system as well as the probability of discontinuity detection has to be evaluated. For example, it is certainly possible to scan a complete tank floor and map the corrosion ultrasonically; however, the cost of performing this may exceed the cost of replacing the tank floor. In this case, there are other less time-consuming and therefore more economical means of accomplishing this task; in this instance, magnetic flux leakage.

A general description of some applications for UT follows.

Thickness measurement

Probably the most common UT application is the measurement of component thickness. The "one side only access" condition for ultrasonic thickness measurement is very desirable. Thickness measurement of tubes and pipes using inside diameter (ID) access can be conducted with either contact transducers or immersion-type systems. The contact systems usually incorporate a device in which the transducer(s) is spring loaded against the tube wall. In the case of immersion systems, either static or revolving transducer(s) scan the tube wall for thinning or corrosion. The data output is either digital or in the form of a "B scan" profile. Thickness measurements are either tabulated or can be determined from the "B scan" type data. Hand-held thickness gauges are usually in abundance at many plant maintenance departments. They are relatively simple to use, very portable, relatively accurate, and also generally inexpensive.

Discontinuity Detection

A discontinuity is an imperfection that may render the component in which it exists unfit for service. It is the time of the formation of the discontinuity that determines the inspection category into which it falls; i.e., whether it is production or service related. Components that are presented for inspection prior to being placed in service are said to be subjected to preservice inspection (PSI). Those components or systems that are to be inspected during service or during plant "shut down season" are said to be subjected to in-service inspection (ISI).

When considering PSI-type discontinuities, cognizant personnel should bear in mind that certain acceptable discontinuities can mask those that may occur in service. An example of this would be a lamination in a pipe near the weld joint. This may cause an "acoustic shadow" that will reflect the sound energy away from a weld discontinuity. Design personnel should be aware of the inspection requirements of their designed components and should also be knowledgeable of the technology of NDT to the extent that it may influence their design philosophies.

Elevated Temperature

In situations where the component is "on line" and shutting down the system is costly, ultrasonic testing can be extremely cost effective; for instance, in cases where a pressure vessel is working to temperature and pressure. Transducers can be designed for either thickness measurement or discontinuity detection at elevated temperatures.

Hydrogen Embrittlement

Hydrogen embrittlement occurs in steel during the solidification process. This is usually due to moisture entrapment and manifests itself as extremely small ruptures close to the grain boundaries. These discontinuities, by nature, are extremely small and usually cannot be detected by most other nondestructive methods. With ultrasonics, the effect of hydrogen embrittlement is to scatter the sound energy. This appears as increased attenuation. The ultrasonic methodology includes the comparison and measurement of apparent attenuation differences in the component. Attenuation is calculated in dB per unit length and measurements are made at the suspected sites. These measurements are compared with a standard section of material that does not contain discontinuties. This process should be conducted with care. Attenuation measurements are made by observing signal amplitude; therefore, transducer contact is critical. Variations in contact or contact area can cause changes in signal amplitude.

Bond Testing

Because there is reflection at an interface, and since the amount of reflection varies with the material on either side of the interface, bond integrity can be assessed with ultrasonic techniques. In its simplest form, the increase in signal height at a bond line will usually indicate a lack of bonding. This is due to a change in the acoustic impedance between the two (or more) layers. A change in impedance also causes a change in the phase of the signal. Special equipment is available that is designed specifically to detect these changes.

Multiple bond layers can be interrogated from one surface. An example of this is multiple layer "skin" on aircraft bodies.

Inaccessible Components

Components that are inaccessible may be inspected remotely using ultrasonic techniques by attaching transducers to rods or manipulators that can be inserted into an opening so that they reach the component to be examined. Examples of these conditions could be high-radiation areas or the rotor shaft within the gearbox of a helicopter, where the component cannot seen without dismantling the gearbox.

Fluid Level Measurement

An ideal method of measuring the level of a fluid in a vessel, pipe, or container is with ultrasonics. Sound passing through the liquid will be transmitted to the opposite side of the container, and the level of the fluid can be established by monitoring the presence or absence of a signal from the opposite side of the vessel. (The opposite side must of course be parallel to the scanning side.) Alternatively, the height of fluid can be monitored by placing a transducer on the bottom of the container and monitoring the signal from the fluid to air interface.

Stress Analyses

The monitoring or measurement of component stress, either residual or induced, can be accomplished with ultrasonic techniques. This is because the sound velocity changes in the material with mechanical strain. Because these changes are relatively small, instrumentation designed for this purpose incorporates extremely accurate velocity measurement timing devices. Stress measurement can be made either along the surface of a component with precision surface wave transducers, or through a section, usually with the use of transducers that oscillate in the "Y" axis and produce shear wave energy in the material. Because shear wave energy is polarized, the direction of stress can be determined by rotating the transducer and observing velocity changes in anisotropic material.

Ultrasonic Extensiometers

High-technology fasteners that have precision tensioning specifications can be tensioned using ultrasonics to measure this parameter. A transducer is sometimes located within a socket wrench and the extension of the bolt being torqued is measured. This is a more accurate tension-measuring device than a conventional torque wrench, as it is not affected by thread friction.

Liquid Flow Rate

Usually used in medical applications, this technique is used industrially when liquid flow rates in pipes must be monitored. This technique usually incorporates a through-transmission configuration where the sound frequency is monitored. Variations in the flow velocity produce changes in the frequency of the sound due to the "Doppler effect."

Other Applications

New applications involving ultrasonic technology evolve almost on a daily basis. With computer technology, the application horizon broadens and is often limited only by the imagination.

VIII. ADVANTAGES AND LIMITATIONS

There is no nondestructive test method that is a panacea. Each method has its advantages and limitations. It is a matter of selecting the test method that offers the most effective approach to solving the examination problem. When determining whether ultrasonics is the most appropriate test method, consideration should be given to the following:

1. Part and geometry to be examined
2. Material type
3. Material thickness
4. Material process—cast, wrought, etc.
5. Type of discontinuities to be detected
6. Minimum discontinuity size to be detected
7. Location of the discontinuities—surface-breaking or internal
8. Orientation of discontinuities (very important when selecting a test technique)
9. Accessibility to areas of interest
10. Surface conditions
11. Type of examination record required

Ultrasonic inspection is ideal for locating small, tight discontinuities assuming the following:

1. The sound energy can be projected at some angle that will respond favorably to the orientation of the reflector.
2. The relationship between the size of the discontinuity and the material's grain structure allows for an acceptable signal to noise ratio.
3. The surface condition is suitable for scanning. A poor scanning surface will not only require a more viscous couplant but possibly the use of a lower test frequency. This may not provide the necessary resolution for the test.

The advantages of ultrasonic examination are as follows:

1. Inspection can be accomplished from one surface
2. Small discontinuities can be detected
3. Considerable control over test variables
4. Varieties of techniques are available using diverse wave modes
5. High-temperature examination is possible with the correct equipment

6. Examination of thick or long parts
7. Inspection of buried parts, e.g., shafts in captivated bearing houses
8. Accurate sizing techniques for surface-breaking and internal discontinuities is possible
9. Discontinuity depth information
10. Surface and subsurface discontinuities can be detected
11. High speed scanning is possible with electronic signal gating and alarm system
12. "Go/No-Go" testing of production components
13. Test repeatability
14. Equipment is light and portable
15. Area evacuation of personnel is not necessary
16. Special licenses are not required as with radiation sources
17. Minimum number of consumables

Some of the limitations of ultrasonic examination are as follows:

1. Discontinuities that are oriented parallel with the beam energy will usually not be detected. Orientation of the discontinuity (reflector) is the most important factor in detecting discontinuities.
2. Discontinuities that are similar to or smaller than the material's grain structure may not be detected.
3. Thin sections may present resolution problems or require the implementation of special techniques.
4. Uneven scanning surfaces can reduce the effectiveness of the test.
5. Signals can be misinterpreted. This includes spurious signals from mode conversion or beam redirection, etc.
6. In general, this method requires a high level of skill and training.
7. Permanent record of the examination results is not typical. The records are limited to physical documentation rather than an actual reproduction of the test, e.g., as is possible with radiography.

IX. GLOSSARY OF TERMS

A-scan—A method of data presentation on an ultrasonic display utilizing a horizontal baseline, that indicates distance, and a vertical deflection from the baseline, that indicates amplitude.

A-Scan presentation—A method of data presentation utilizing a horizontal baseline to indicate distance, or time, and a vertical deflection from the baseline to indicate amplitude.

Amplitude—The vertical height of a signal, usually base to peak, when indicated by an A-scan presentation.

Angle beam—A term used to describe an angle of incidence or refraction other than normal to the surface of the test object, as in angle beam examination, angle beam search unit, angle beam longitudinal waves, and angle beam shear waves.

Area amplitude response curve—A curve showing the relationship between different areas of reflection in an material and their respective amplitudes of ultrasonic response.

Attenuation—A factor that describes the decrease in ultrasound intensity or pressure with distance. Normally expressed in decibels per unit length.

B-scan presentation—A means of ultrasonic data presentation that displays a cross section of the specimen, indicating the approximate length (as detected per scan) of reflectors and their relative positions.

Back reflection—An indication, observed on the display screen of a UT instrument, that represents the reflection from the back surface of a reference block or test specimen.

Back echo—See *back reflection.*

Back surface—The surface of a reference block or specimen that is opposite the entrant surface.

Beam spread—A divergence of the ultrasonic beam as it travels through a medium.

Bubbler—A device using a liquid stream to couple a transducer to the test piece.

C-scan—An ultrasonic data presentation that provides a plan view of the test object and discontinuities.

Collimator—A device for controlling the size and direction of the ultrasonic beam.

Contact testing—A technique in which the transducer contacts directly with the test part through a thin layer of couplant.

Couplant—A substance, usually a liquid, used between the transducer unit and test surface to permit or improve transmission of ultrasonic energy.

Critical angle—The incident angle of the ultrasonic beam beyond which a specific refracted wave no longer exists.

DAC—Distance amplitude correction. Electronic change of amplification to provide equal amplitude from equal reflectors at different depths. Also known as swept gain, time corrected gain, time variable gain, etc.

DAC curve—A curve (usually drawn on the screen) derived from equal reflectors at different depths.

Damping, search unit—Lmiting the duration of a signal from a search unit subject to a pulsed input by electrically or mechanically decreasing the amplitude of successive cycles.

dB control—A control that adjusts the amplitude of the display signal in decibel (dB) units.

Dead zone—The distance in the material from the surface of the test specimen to the depth at which a reflector can first be resolved under specified conditions. It is determined by the characteristics of the search unit, the ultrasonic instrumentation, and the test object.

Decibel (dB)—Logarithmic expression of a ratio of two amplitudes or intensities. (UT) $dB = 20 \log_{10}$ (amplitude ratio).

Delay line—A column of material such as Plexiglas that is attached to the front of a transducer. It behaves similarly to a water path and allows the initial pulse to be shifted off the scree. This often improves "near surface resolution."

Delay sweep—An A-scan or B-scan presentation in which an initial part of the time scale is not displayed.

Discontinuity—A lack of continuity or cohesion; an intentional or unintentional interruption in the physical structure or configuration of a material or component.

Distance amplitude, compensation (electronic)—The compensation or change in receiver amplification necessary to provide equal amplitude on the display of an ultrasonic instrument for reflectors of equal area that are located at different depths in the material.

Distance amplitude, response curve—See *DAC.* A curve showing the relationship between the different distances and the amplitudes of an ultrasonic response from targets of equal size in an ultrasonic transmitting medium.

Distance linearity range—The range of horizontal deflection in which a constant relationship exists between the incremental horizontal displacement of vertical indications on the A-scan presentation and the incremental time required for reflected sound to pass through a known length in a uniform transmission medium.

Doppler effect—The change in frequency of a sound wave due to movement of the reflector. Movement toward or away from the sound will result in a change in frequency (e.g., the tone of a train whistle changing as the train passes).

Dual search unit—A search unit containing two elements, one a transmitter, the other a receiver.

Dynamic range—The ratio of maximum to minimum reflective areas that can be distinguished on the display at a constant gain setting.

Entrant surface—The surface of the material through which the ultrasonic waves are initially transmitted.

Far field—The zone of the beam (beginning at the Y_0 point) where equal reflectors give exponentially decreasing amplitudes with increasing distance.

Flaw—A discontinuity in a material or component that is unintentional.

Flaw characterization—The process of quantifying the size, shape, orientation, location, growth, or other properties of a flaw based on NDT response.

Frequency (examination)—The number of cycles per second (Hz).

Frequency, pulse repetition—The number of times per second that a search unit is excited by the pulser to produce a pulse for ultrasonic imaging. This is also called pulse repetition rate or pulse repetition frequency (PRF).

Gate—An electronic means of selecting a segment of the time range for monitoring, triggering an alarm, or further processing.

Immersion testing—An ultrasonic examination technique in which the search unit and the test part are submerged (at least locally) in a fluid, usually water.

Impedance, acoustic—A mathematical quantity used in computation of reflection characteristics at boundaries. It is the product of wave velocity and material density (ρc).

Indication—A response or evidence of a response disclosed through an NDT that requires further evaluation to determine its full and true significance.

Initial pulse—The response of the ultrasonic system display to the transmitter pulse (sometimes called "main bang").

Lamb wave—A specific mode of propagation in which the two parallel boundary surfaces of the material under examination (such as a thin plate or wall of a tube) establish the mode of propagation. The Lamb wave can be generated only at particular values of frequency, angle of incidence, and material thickness. The velocity of the wave is dependent on the mode of propagation and the product of the material thickness and the examination frequency.

Linearity, amplitude—A measure of the proportionality of the amplitude of the signal input to the receiver and the amplitude of the signal appearing on the display of the ultrasonic instrument or on an auxiliary display.

Linearity, time or distance—A measure of the proportionality of the signals appearing on the time or distance axis of the display and the input signals to the receiver from a calibrated time generator or from multiple echoes from a plate or material of known thickness.

Longitudinal wave—A wave in which the particle motion of the material is essentially in the same direction as the wave propagation. (also called compressional wave).

Metal path—See *Sound path*

Mode—The type of ultrasonic wave propagating in the material as characterized by the particle motion (e.g., longitudinal, transverse, etc.)

Mode conversion—Phenomenon by which an ultrasonic wave that is propagating in one mode refracts at an interface to form ultrasonic wave(s) of other modes.

Multiple back reflections—Successive signals from the back surface of the material under examination.

Near field—The region of the ultrasonic beam adjacent to the transducer having complex beam profiles and intensity variations. Also known as the Fresnel zone.

Noise—Any undesired signal (electrical or acoustic) that tends to interferes with the interpretation or processing of the desired signals.

Normal incidence (also see *Straight beam*)—A condition in which the axis of the ultrasonic beam is perpendicular to the entrant surface of the part being examined.

Penetration depth—The maximum depth in a material from which usable ultrasonic information can be obtained and measured.

Probe—See *Search unit.*

Pulse-echo technique—An examination method in which the presence and position of a reflector are indicated by the echo amplitude and time.

Pulse length—A measure of the duration of a signal as expressed in time or number of cycles.

Range—The maximum distance that is presented on a display.

Rayleigh wave—An ultrasonic surface wave in which the particle motion is elliptical and the effective penetration is approximately one wavelength.

Reference block—A block of material that includes reflectors. It is used both as a measurement scale and as a means of providing an ultrasonic reflection of known characteristics.

Reflector—An interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least part of the sound is reflected.

Reject, suppression—A control for minimizing or eliminating low-amplitude signals (electrical or material noise) so that true signals are emphasized.

Relevant indication—An indication caused by a discontinuity that requires evaluation.

Scanning—The movement of a transducer relative to the test part in order to examine a volume of the material.

Search unit—An electroacoustic device used to transmit and/or receive ultrasonic energy. The device generally comprises a piezoelectric element, backing, wearface and/or wedge. Sometimes known as a “probe” or “transducer.”

Sensitivity—A measure of the smallest reflector that produces a discernible signal on the display of an ultrasonic system.

Shear wave—wave motion in which the particle motion is perpendicular to the direction of propagation (transverse wave).

Sound path—The path of the sound energy from the time that it leaves the transducer and reflects back to the transducer.

Skip distance—In angle beam testing, the distance along the test surface from sound entrant point to the point at which the sound returns to the same surface. It can be considered the top surface distance of a complete “vee” path of sound in the test material.

Transducer—A piezoelectric element used to produce ultrasonic vibrations.

Through-transmission technique—A technique in which ultrasonic waves are transmitted by one search unit and received by another at the opposite surface of the material being examined.

Vee path—The angle beam path in materials starting at the search-unit examination surface, through the material to the reflecting surface, continuing to the examination surface in front of the search unit, and reflecting back along the same path to the search unit. The path is usually shaped like the letter V.

Water path—The distance from the transducer to the test surface in immersion or water column testing.

Wedge—In angle beam examination by the contact method, a device used to direct ultrasonic energy into the material at an angle.

Wheel search unit—An ultrasonic device incorporating one or more transducers mounted inside a liquid-filled flexible tire. The beam is coupled to the test surface through the rolling contact area of the tire. Also known as a "wheel probe" or "roller search unit."

X. REFERENCES

J. C. Drury, *Ultrasonic Flaw Detection for Technicians,* Ninth Edition, OIS plc, Stockton-on-Tees, Cleveland, U.K., 1997.

Nondestructive Evaluation and Quality Control, ASM International Metals Handbook, Ninth Edition, 1989.