Ultrasonic technicians have varied experience and analytical skills. The more exposure to different signal characteristics, techniques and indication images, the better their analysis skills will be. During the period when the technician is accumulating the experience and skills, there must be an oversight process for the thorough and proper evaluation of indications and to minimize false calls.

In the chemical industry, ammonia pressure vessels have a history of extensive weld cracks. Detection and evaluation is conducted by using advanced ultrasonic techniques such as time of flight diffraction (ToFD), phased array ultrasonics and high temperature angle beam ultrasonics. The time of flight diffraction technique is more effectively used for high temperature scanning.

Initial Inspections Using Phased Array Ultrasonic Testing

The following case involved a pressure vessel within a cluster of ammonia plants. An initial inspection was conducted at ambient temperature during a plant shutdown. Phased array ultrasonic testing was conducted on a total of six meridian welds (sometimes described as orange peel welds) of a vessel's bottom head (Fig. 1).

The technician reported cracks on all six of the welds. Based upon the findings, the client evaluated fitness for service and determined that it was safe to operate the vessel with the reported cracks. Periodic monitoring was required as a condition of continued operation.

Periodic Monitoring Utilizing Time of Flight Diffraction

The periodic monitoring was conducted while the plant was operating by an inspection crew specializing in onstream or online inspection. The online examination was conducted at 291 °C (556 °F),

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using time of flight diffraction. This time however, no cracks were reported (Fig. 2). The inspection company’s Level III analyst reviewed the test data and confirmed that there was no evidence of cracking. Additional testing was conducted using conventional ultrasonic shear wave angle beam examination. Again no cracks were reported.

Understandably, the client was concerned. Why were time of flight diffraction and the conventional ultrasonic shear wave angle beam that followed unable to find the cracks originally reported by phased array ultrasonics? Did the high temperature affect the inspection? The Level III analyst requested the original ultrasonic phased array inspection data, but none had been retained. The original report however, was available and showed each crack to be of the same length and in the same location on each of the six welds. The Level III analyst then suggested the client review the construction drawings for the vessel. It was discovered these locations corresponded to internal attachment welds on the original drawings.

These indications at the attachment welds appeared later in time (at a greater distance) than that of the vessel head internal surface. The findings were demonstrated to the client. It had become clear that the reported cracks were in fact signals from the attachment welds.

**Solution**

Advanced ultrasonic methods such as phased array ultrasonics and time of flight diffraction, require extensive training and experience. Time of flight diffraction uses a different approach from conventional ultrasonic testing. One transducer transmits the ultrasonic energy which insonifies the area of interest. The other transducer

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**Tech Toon**

![Tech Toon Image](image-url)

**Figure 2.** Scan for time of flight diffraction ultrasonic tests conducted during periodic online monitoring showing no indications in area previously interpreted as crack.
functions as a receiver, collecting the sound wave and the instrumentation records images from any tip-diffracted signals. Interpretation requires experience and access to images of many signals from different types of discontinuities. Phased array ultrasonics can scan through a range of angles electronically, which is the equivalent of making multiple angle beam shear wave scans at different angles.

Prior to making a statement about a significant crack which could cause shutdown of a plant and have significant financial ramifications, a technician should call upon a review by a more experienced technician or analyst. In many companies, the Level III supervisor reviews all time of-flight diffraction, phased array ultrasonic testing and advanced data prior to issuing a conclusion.

Moral of the Story

Don’t make a critical call without back up analysis, either by expert review or by confirmation of results using other methodologies. If original design drawings or vessel fabrication records are available, they can be a valuable resource to confirm part geometries or other fabrication issues that may not be readily apparent. If images occur at regular intervals, geometry or internal attachments may be the source of the signal. Crack images typically have specific characteristics, due to their irregular shape, as well as variable lengths and depths. Above all, advanced ultrasonic processes have recordable images that can easily be retained digitally and transmitted by e-mail to an experienced analyst for confirmation.

NDT GLOSSARY

Ultrasonic Testing

angle beam: Ultrasound beam traveling at an acute angle into a medium. The angle of incidence or angle of refraction is measured from the normal to the entry surface.

back reflection: Signal received from the far boundary or back surface of a test object.

diffraction: Deflection of a wavefront when passing the edge of an ultrasonically opaque object.

insonification: Irradiation with sound.

phased array: Mosaic of transducer elements in which the timing of the elements’ excitation can be individually controlled to produce certain desired effects, such as steering or focusing the beam.

reflection: General term for the process by which the incident energy leaves a surface or medium from the incident side, without change in frequency. Reflection is usually a combination of specular and diffuse reflection.

time of flight: Time for an acoustic wave to travel between two points. For example, the time required for a pulse to travel from the transmitter to the receiver via diffraction at a discontinuity edge or along the surface of the test object.

transverse wave: Type of wave in which the particle motion is perpendicular to the direction of propagation. Also called shear wave.

ultrasonic: Of or relating to acoustic vibration frequencies greater than about 20 kHz.

ultrasonic testing: Method of nondestructive testing, using acoustic waves at inaudibly high frequencies at the interrogating energy.

UT: Abbreviation for the ultrasonic method of nondestructive testing.

Glossary entries adapted from the Nondestructive Testing Handbook.
This is the second in a series of three articles addressing ultrasonic weld inspection as it pertains to the oil and gas industries. The goal of the series is to improve results in performance demonstration tests such as the American Petroleum Institute (API) Qualification of Ultrasonic Examiners Certification Program (QUTE) test and others required by leading oil companies.

Identifying the Source of an Indication

What is the source of an indication? Does the reflector result from weld geometry or an actual discontinuity? Once it has been determined that an indication is from a discontinuity, it must be characterized. This process consists of determining the location of the discontinuity by plotting the beam sound path on a cross section of the weld and then observing its signal characteristics.

Plotting Discontinuities

Ninety percent of the battle in discontinuity identification is in knowing where the discontinuity is located. Accurate plots are critical in determining the cross sectional position of a discontinuity. When calibrating an angle beam probe, it is essential to measure the exit point and actual refracted angle since they will both change as the wedge wears. Indications must always be plotted. Relying solely on the surface distance and depth information from the discontinuity detector can often result in misidentifying a discontinuity or mistaking geometry for a discontinuity.

Before plotting, a cross section of the weld must be drawn. A contour gage should be used to record the profile of the weld cap (Fig. 1). The geometries of test plates used in most performance demonstration tests are typically very consistent, so obtaining a single profile from the weld cap on any given weld is usually sufficient for plotting all indications. The geometry of field welds however, can be wildly erratic and it is therefore very important to obtain a profile from each indication location when doing field inspections. Using a contour gage will make any mismatch or misalignment plainly evident once the bottom surface is drawn in.

After obtaining a profile of the weld cap, thickness measurements must be obtained on the weld cap and on both sides of the weld. The opposite surface of the part can now be drawn. For single-V welds, a gap of 2.54 mm (0.1 in.) should be left on the far surface. This area is known as the weld root.

It is recommended that fusion lines not be drawn in when examining test plates. Top surface weld toes on test plates often overlap the bevel. Assuming that the bevel is at the toe can lead to incorrectly identifying lack of sidewall fusion as slag.

Figure 1. Contour gage used to obtain weld profile.
If a discontinuity is plotted in the root area or in the fusion line, it is likely to be a planar discontinuity such as a crack, lack of fusion, or lack of penetration. If the discontinuity is plotted in the body of the weld, it is likely to be a volumetric discontinuity such as slag or porosity, with a centerline crack being the exception. Many performance demonstration tests only require you to be able to tell the difference between planar and volumetric discontinuities. Additional guidelines include the following.

- Whenever possible, plot indications from both sides of the weld.
- Plot in both the first and second legs.
- Use different angles since the response of an indication to different angles can indicate the orientation of a discontinuity.

Discontinuity Signal Characteristics

Practice is the best way to learn signal characteristics. Kits are commercially available with small plates containing weld discontinuities. Each plate has a different type of weld discontinuity accompanied by a cross section of it.

Gain settings should be at reference level and the probe should be moved very slowly when examining signal characteristics. When looking at indication signals, the following questions should be asked:

- Is the signal clean and sharp or is it jagged?
- What happens when the probe is skewed? Does the signal immediately drop away or does it remain?
- What happens when you move the probe towards and away from the discontinuity?
- What angle responds best?
- Are there multiple peaks?
- Are there trailing echoes?
- Are there tip-diffracted signals?

Indications Caused by Geometry

Indications caused by the weld root or weld cap are easy to determine by plotting alone. Another common situation from both the weld root and the weld cap is illustrated in Fig. 2a. Point A occurs when a signal is returned from the root. Point B produces an indication that typically shows up about half way through the second leg. This is caused by the beam hitting the root and then reflecting straight up to

![Figure 2. Plots of geometry indications: (a) root and cap; (b) mismatch or misalignment.](image)

![Figure 3. Slag or porosity: (a) plot; (b) signal characteristics.](image)

![Figure 4. Signal for porosity.](image)

FYI continued on page 6.
the weld cap. This is easily identified because the surface distance reading on the discontinuity detector will put it in the plate on the far side of the weld.

In the case of a mismatch (Fig. 2b), there will be an indication from the weld root geometry from one side of the weld (plot A) and not the other (plot B). With misalignment, the weld root indication will be visible from one side of the weld for half the circumference of a pipe or vessel and from the other side of the weld on the other half.

**Slag**

**Plot.** Depending on the location, slag will plot in the first and second legs (usually in the body of the weld) and should show volume (Fig. 3a). It can sometimes be seen using a 0 degree probe from the weld cap surface. If it plots directly in the centerline, signal characteristics become critical; it could be a centerline crack.

**Signal Characteristics.** Signal characteristics can be low in amplitude and will usually have a small trailing echo, very similar to one produced by side drilled holes. The signal usually drops off relatively quickly when the probe is skewed.

**Porosity**

**Plot.** The plot for porosity is similar to slag (Fig. 3a).

**Signal Characteristics.** Signal characteristics for porosity are usually a low-amplitude, wide, hashy signal that will remain, or walk when the probe is skewed. Porosity can appear as multiple signals as well. Porosity is probably the easiest discontinuity to miss. Discontinuity detection scans should be conducted 12 dB hot for this reason (Fig. 4).

**Centerline Crack**

**Plot.** Centerline cracks will plot the same as slag and porosity (Fig. 3a) except the plots from each side of the weld should be closer together, indicating a narrower discontinuity.

**Signal Characteristics.** The signal for a centerline crack will likely appear rough and be wider than slag but can be similar to porosity (Fig. 5). When the probe is skewed, the signal will remain and walk a little. Signal discrimination and finite plotting are vital in distinguishing the difference between porosity and sidewall cracks. Porosity usually displays more peaks than a crack.

**Lack of Sidewall Fusion (LOSWF)/Sidewall Crack**

**Plot.** As seen in Fig. 6a, lack of sidewall fusion or sidewall cracks should plot in the second leg from the same side that the discontinuity is on (plot A). When looking in the first leg from the same side (plot B), it is typically not visible, although a 70 degree probe can sometimes get a very small signal. Occasionally, when looking from the first leg on the same side, a signal will be received that plots out similar to plot B1. This happens when the beam hits the lack of fusion and bounces straight down to the bottom surface of the plate (plot B2). From the opposite side of the weld, it will not be visible in the second leg and will only be visible

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FYI continued from page 5.

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FYI continued on page 8.

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Figure 5. Signal for centerline crack.

Figure 6. Lack of sidewall fusion: (a) plot; (b) signal.
Find Cracks Fast
Fluorescent and Visible Penetrant Inspection Materials since 1952
available through authorized distributors

Penetrants formulated for quality requirements:
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from the first leg if the lack of sidewall fusion is low enough toward the weld root (plot C).

Because the surface of a sidewall crack is rough and faceted, it is probable that the signal will be picked up from some or all of the locations where lack of sidewall fusion can’t be used.

LOSWF Signal Characteristics. Lack of sidewall fusion should be the discontinuity that is easiest to identify. The signal is usually very high in amplitude and very clean and sharp (Fig. 6b). Also, when the probe is skewed, the signal immediately drops straight off instead of walking a little. Because bevels are usually around 30 degrees, the sound beam reflector will typically respond best to 60 degrees (this places the beam at 90 degrees to the discontinuity).

Sidewall Crack Signal Characteristics. The signal for sidewall cracks will likely appear rough and be wider than lack of sidewall fusion. When the probe is skewed, the signal will remain and walk a little. As with lack of sidewall fusion, the signal is typically high in amplitude and responds best to 60 degrees.

Root Cracks and Lack of Root Fusion (LORF)

Plot. Root cracks and lack of root fusion will plot in the root area on one side of the root (Fig. 7a). It is important to plot from both sides of the weld when possible because the plots should show that the discontinuity is on the same side of the root and that it is narrow.

Signal Characteristics. Signal characteristics are the distinguishing factor between root cracks and lack of root fusion, although discerning the difference can still be difficult. However, most performance demonstration tests and the ASME code only require the ability to distinguish planar discontinuities from volumetric discontinuities. With cracks, the facets of the cracks are usually visible along with a tip diffracted signal and when the probe is skewed, the signal will remain longer than the signal for lack of root fusion. The reflector signal will also have a wider base than lack of root fusion. Lack of root fusion characteristics will

Figure 7. Root crack or lack of root fusion: (a) plot; (b) signal for root crack; (c) signal for lack of root fusion.

Figure 8. Lack of root penetration: (a) plot; (b) signal.
Crossword Challenge

Ultrasonic Testing of Welds

Across

4. This type of reference block is easily transported in the field.
6. Measurement unit of sound energy.
7. Sound ___ traveled at an angle from transducer exit point to discontinuity.
10. Description of raster scan transducer sequence.
14. A _____ wave examination of the parent material on each side of the weld is the primary examination prior to angle beam examination of the weld.
16. Incomplete bonding of the weld metal to the side of the original weld groove is called sidewall lack of _____.
19. Area of weld where lack of penetration occurs.
21. _____ in the parent material could alter the sound path.

Down

1. Weld ____; a pre-inspection requirement for drawing weld plot.
2. Imaginary line along the longitudinal direction of weld.
3. The velocity of shear wave propagation is approximately ____ the velocity of compression wave propagation.
5. Distance along surface equivalent to one full V path.
8. This kind of crack is located where the crown of the weld meets the parent material.
9. Description of crack at right angle to longitudinal axis of the weld.

11. In a longitudinal sound wave, particle motion is classified as being in two zones, either _____ or compression.
12. Category of discontinuity that includes porosity and slag.
13. Category of discontinuity that includes cracks and lack of fusion.
15. Description of the transducer movement to and from the weld.
17. Area of weld where slag is usually detected.
18. Wave mode of ultrasonic propagation usually applied to ultrasonic weld examination.
20. Area adjacent to weld affected by heat.

Answers

Crossword Challenge

Ultrasonic Testing of Welds

Across

4. DSC
6. decibel
7. path
10. overlap
14. compression
16. fusion
19. root
21. lamination

Down

1. width
2. axis
3. half
5. skip
8. toe
9. transverse
11. rarefaction
12. volumetric
13. planar
15. scanning
17. body
18. shear
20. HAZ
be similar to lack of sidewall fusion but can be rougher and walk a little more.

Lack of Root Penetration (LOP)

Plot. Lack of root penetration will plot on each side of the root (Fig. 8a) and is typically visible with a 0 degree probe from the weld cap surface.

Signal Characteristics. The signal for lack of root penetration typically has a wide base and is high in amplitude. Its signal usually persists briefly when the probe is skewed.

Conclusion

A contour gauge and careful plotting, followed by the detailed discrimination of signal characteristics, will determine the location and reveal the identity of a discontinuity. Additionally, if the proper training pieces are made available to technicians and the steps recommended in this text are followed, the results of industry performance demonstration tests, as well as the quality of work done in the field, should show commensurate improvement.
Q. I have an ultrasonic inspection question about accuracy and best performance when I check in the middle of a flange of an IPE (medium size flange I-beam manufactured according to Euronorm 19-57 standard) or HEA (European acronym for wide flange I-beams) girder. Is this signal of flaw true or what is the percent of error in this measurement? Thanks for your help. GAV.

A. This is a question that you need ask your Level III, as I do not know the exact configuration of the material you are inspecting. However, based on personal experience, if the welds you are inspecting are on typical beam-to-column flange connections as shown below, cope holes are often cut in the end of the beam web beneath the upper flange weld to allow the insertion of a backing bar, and above the lower beam flange to allow the welder access to weld the area in the center of the flange. When testing such weld configurations, it is possible to move the transducer back far enough from the weld so that the sound beam picks up the edge of the cope hole (point A in Fig. 1). This will often result in a very large signal on the CRT (cathode ray tube) screen at a sound path similar to that of a large root reflector. There are two ways to determine if this signal is a cope hole reflector. First, if you calculate the sound path versus the surface distance (from the transducer exit point to the weld), you will see that the surface distance is too great for the reflector to be in the weld. Second, you can see if the signal can be damped using a couplant-wet finger. In the damping process, you maximize the signal on the screen and reduce the gain until the top of the signal is on the screen, then wet a finger and tap the junction of the cope hole and the flange (point A) with that finger. If that is the point where the signal originates, some of the sound will travel into your wet finger, reducing the sound returning to the screen signal and lowering the amplitude of the signal. When you remove your finger, the signal should go back to the original screen amplitude. Tapping point A should cause the amplitude to bounce up and down in time with the tapping, indicating that this is the source of the return signal, which is an irrelevant signal caused by part geometry.

Again, your Level III should be able to demonstrate this process to you and is the person that should confirm that the signal is irrelevant.

Q: I am a military veteran and would like to know if the ASNT examinations are approved for GI Bill reimbursement, and if so, how do I go about applying for it? AW.

A: Yes, ASNT NDT Level III and IRRSP examinations have all been approved by the Veterans Administration for reimbursement. Eligibility requirements can be found online at www.gibill.va.gov/resources/education_resources/programs/licensing_and_certification.html. On that page under How to Find Approved License & Certification Tests, you can click on the Search for approved tests link and the WEAMS (Web Enabled Approval Management System) search page will come up. To find the ASNT NDT Level III exams, select LAC Category Type as either Certification or Both, leave the L&C Name block empty then click on Ohio on the map (ASNT is located in Ohio), which will bring up the list of licensure and certification programs that have been approved by the Ohio Department of Education for VA reimbursement. Clicking on Non Destructive Testing NDT Level III will bring up our ASNT NDT Level III exams and clicking on Industrial Radiography Radiation Safety Personnel will bring up our IRRSP exam information. Reimbursement is currently $250.00 per examination.

According to the VA’s L&C pamphlet, you are eligible for reimbursement if you qualify for the Montgomery GI Bill (MGB or MGB-SR), the Reserve Education Assistance Program (REAP), the Veterans Educational Assistance Program (VEAP) or Dependents Educational Assistance (DEA). The Veterans Administration asks that you submit your reimbursement request within one year of when the test was taken.

Respectfully,
James W. Houf,
Senior Manager, ASNT Technical Services Department

E-mail, fax or phone questions for the “Inbox” to the Editor: lhumphries@asnt.org, fax (614) 274-6899, phone (800) 222-2768 X206.
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