Circumferential Scanning in Ultrasonic Inspection

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Conventional contact ultrasonic inspection is typically performed on relatively flat surfaces. Indications for common configurations such as welded plates and T and Y connections can be plotted and located with ease. In many cases newer ultrasonic units will even do the calculations for the inspector as long as accurate information for wedge angle, wall thickness, wedge delay, and in some cases, the outside diameter (OD) and inside diameter (ID) is input into the ultrasonic unit. However, on those occasions when inspection is performed in the circumferential direction, consideration should be given to what the sound beam is actually doing in the test specimen.

When conducting circumferential scans, it is important to understand that the sound path for one leg of sound is going to be increased based on the ratio of the inside diameter to the outside diameter. If the refracted (inspection) angle selected is too great, a vee path will not exist and a complete inspection of the cross section will be impossible to achieve. Figure 1 shows the differences between a flat scan and a circumferential scan using the same refracted angle. As can be seen, both the sound path and the surface distance are greater for a curved part than for a flat part of the same thickness.

Flat Plate Calculations

Sound paths, surface distances and discontinuity depths on flat plate can be determined by using the following standard trigonometric formulas. All calculations are based on the centerline of the sound beam and do not take beam spread into account (Fig. 2). Equation 1 is

\[
\text{Equation 1}
\]

Figure 1. Differences between flat scan and circumferential scan sound paths using the same angle on material of the same thickness.

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used to calculate the first leg or half-skip distance of the sound path from the exit point to point A.

\[
\text{First leg sound path} = \frac{t}{\cos \theta}
\]

Equation 2 is used to calculate the full-skip distance from the exit point down to point A and back up to point B. The full-skip distance can also be found by doubling the first leg sound path.

\[
\text{Full skip distance} = 2t \times \tan \theta
\]

Equation 3 is used to calculate surface distance.

\[
\text{Surface distance} = \text{Sound path} \times \sin \theta
\]

Discontinuity depth can be calculated in several ways. Equation 4 can be used calculate discontinuity depth for discontinuities in the first leg only.

\[
\text{Discontinuity depth} = \text{Sound path} \times \cos \theta
\]

Equation 5 can be used to calculate discontinuity depth for discontinuities in the second leg only.

\[
\text{Discontinuity depth} = 2t - (\text{Sound path} \times \cos \theta)
\]

**Examples**

**Discontinuity In First Leg.** A signal is noted at 1.5 in. (3.81 cm) using a 70° transducer on a 0.75 in. (1.91 cm) part. Substituting values into Eq. 1:

\[
\text{First leg sound path} = \frac{t}{\cos \theta} = \frac{0.75 \text{ in.}}{0.342} = 2.19 \text{ in.}
\]

where 1.0 in. is equal to 25.4 mm. This shows that the indication is in the first leg. So, discontinuity depth will be determined using Eq. 4.

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Figure 2. Sound path in angle beam testing of flat plate.
Discontinuity In Second Leg. A signal is noted at 3.2 in. (8.13 cm) using a 70 degree transducer on a 0.75 in. (1.91 cm) part. Since the sound path is greater than 2.19 in. (5.56 cm) but less than 4.38 in. (11.13 cm) or twice the length of the first leg sound path as calculated in the first example, the indication is in the second leg. Discontinuity depth will be determined using Eq. 5.

\[
\text{Discontinuity depth} = \text{Sound path} \times \cos \theta
\]

\[
= 1.5 \text{ in.} \times 0.34
\]

\[
= 0.513 \text{ in.}
\]

Circumferential Calculations

If we now add curvature to the part, we must take into consideration the changes to our sound path due to part radius and wall thickness. Equation 9 is used to calculate surface distance in a curved part:

\[
\text{Surface distance} = \frac{\pi R_2}{90} \left[ \sin^{-1} \left( \frac{R_2}{R_1} \sin \theta \right) - \theta \right]
\]

where \( R_1 \) is the inside diameter radius, \( R_2 \) is the outside diameter radius and \( \theta \) is the angle of refraction (Fig. 3).

The calculation of the surface distance and skip distance for a circumferential scan is quite different from that for a flat plate as described earlier. Because few individuals want to tackle such calculations, another more practical method uses an ID/OD notched sample. This approach is frequently used to verify that the sound path is reaching the inside diameter of the part and can aid in determining or verifying distances of sound paths in the circumferential direction. To ensure that the full thickness of the curved part is inspected, the refracted angle must be small enough to reflect off the inside diameter surface. Otherwise, the inside diameter of the part may be missed. Equation 10 or 11 can be used to determine the angle required to reach the inside diameter of a part:

\[
\sin \theta = 1 - \left( \frac{2t}{\text{Outside diameter}} \right)
\]

where \( t \) is the maximum thickness and \( \theta \) is the transducer angle.

\[
\frac{\text{Inside diameter}}{\text{Outside diameter}} \sin^{-1} = \theta_{\text{max}}
\]

Circumferential scanning equations allow the calculation of the appropriate probe angle to examine the bore of any given pipe. Another way of analyzing this problem is to determine the thickest wall that can be inspected. Equation 12 can be used to determine the maximum wall thickness for a given angle:

\[
\text{Outside diameter} \times \left(1 - \sin \theta\right)
\]

where \( t \) is maximum wall thickness and \( \theta \) is the transducer angle. Again, this will ensure that the center of the sound beam will reach the inside diameter of the part.

An inside diameter notch on a part with the same dimensions and diameter as the specimen to be inspected can also be used to determine the appropriate angle. This is a more practical approach to verify that the angle used is correct and the unit is properly adjusted or calibrated (standardized). Another practical method for verifying sound paths is to draw or plot the actual dimensions on paper. Doing so makes it easier to visualize the sound beam in the part.

Caution should be exercised when selecting the transducer. The size of the transducer in relation to the radius of the part is extremely important. The contact surface between the transducer and the part is reduced when the radius of the part is small and the transducer size is increased. This condition has an adverse affect on the results of the inspection. Much of the coupling efficiency is lost due to the small contact surface between the transducer and the part when this condition exists. In some cases it is necessary to have a contoured wedge so as to minimize this condition.

Figure 3. Sound paths for correct and incorrect refracted angles.
It is obvious that the center of the ultrasonic beam needs to reach the inside diameter of the part to ensure a complete inspection. Thus, it is important to consider the beam divergence or beam spread. Signal amplitude will be maximized when the center portion of the beam reaches any reflector and since that is the case it is necessary to assure full coverage of the cross-section in order to detect any discontinuities emanating from the inside diameter of the part.

Circumferential scanning occurs more often than one might think. Even when performing ultrasonic inspections in the longitudinal direction on pipe or other cylindrical parts (especially welds), a circumferential scan is required. A scan of a pipe weld for transverse discontinuities would also require a circumferential scan parallel to the axial direction of the weld.

Because ultrasonic inspection is a volumetric inspection, the technician must confirm that the complete volume of the test piece is being adequately inspected. Test specifications need to be consulted. Discontinuities located at the surface are the most detrimental. Technicians must be sure that when performing ultrasonic inspection on pipe in the circumferential direction they are able to provide a full volumetric inspection by covering the inside diameter and the outside diameter.

References:

