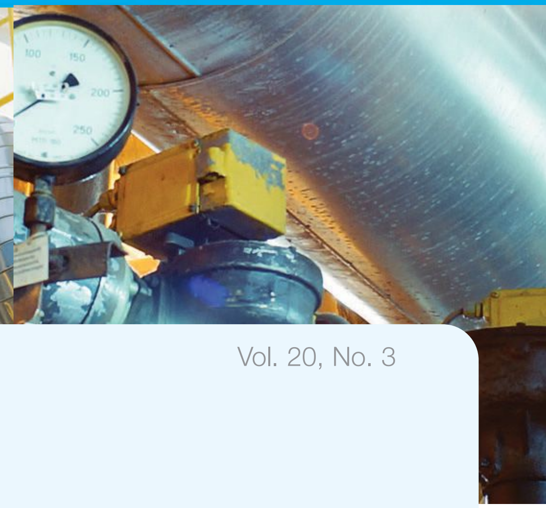
The NDT Technician



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FOCUS

Using Passive-Axis Focusing Wedges to Decrease Inspection Reject Rates

by Simon Alain and Nicolas Badeau

When pipe welds are inspected using phased array ultrasonic testing (PAUT), the common problem of beam divergence is amplified by the curved geometry. To compensate the adverse effects of beam divergence in curved parts, a focusing wedge can be used.

Many acoustic and inspection setup parameter validations are performed on flat blocks or plates even though the inspections are conducted on curved surfaces. Since the beam is affected by the radius of curvature at the various interfaces (for example, the wedge-to-part interface and back wall interface), the response to a discontinuity measured on a plate can be quite different from the response measured on a pipe. Recently developed passive-axis focusing (PAF) wedge technology can be used to address this challenge.

When an ultrasound beam propagates through a curved surface, the interface acts as a converging or diverging lens depending on the medium's velocity ratio. In most typical nondestructive testing (NDT) applications, the ultrasound passes from a low-velocity medium (such as a Rexolite wedge) to a high-velocity medium (such as carbon steel) through a convex interface like an external pipe surface. This results in a diverging lens effect that causes the beam width to broaden. The images shown in Figure 1 illustrate beam simulations showing the differences between the beam in the passive axis on a flat surface (Figure 1a) and its equivalent when entering a 4.5 in. (11.43 cm) outside diameter (OD) surface (Figure 1b). The first medium is Rexolite (which has a pressure wave velocity of 2330 m/s), and the second medium is carbon steel (which has a shear wave velocity of 3240 m/s).

As illustrated in Figure 2, the inside diameter (ID) surface (or back wall) of the pipe acts as yet another diverging lens, broadening the beam even more.

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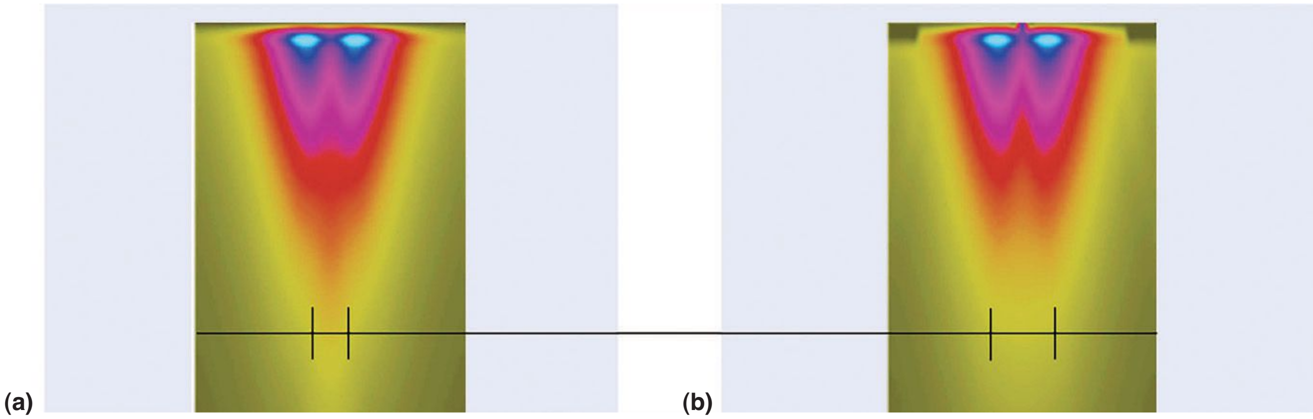

Figure 1. Beam simulation: (a) flat plate; (b) 4.5 in. (11.43 cm) OD pipe.

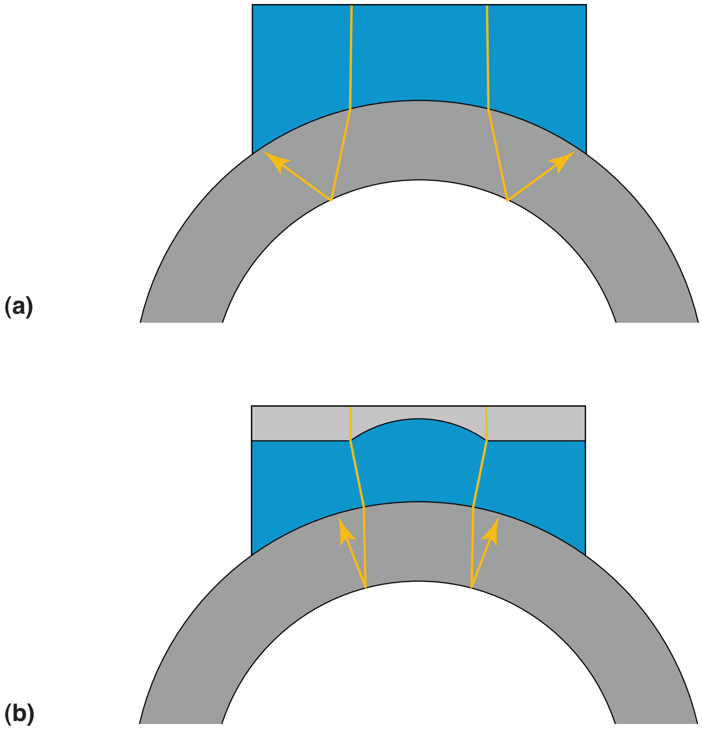

Figure 2. Beam divergence path: (a) a standard wedge; (b) passive-axis focusing wedge.

Importance of the Beam Width for Scan Length Measurement

In most NDT applications, including girth weld inspection, the scan direction is along the phased array probe's passive axis, and the discontinuity length measurement is performed using an encoded system. The most commonly used amplitude-based sizing method is the 6 dB drop technique. The advantage of this technique is that the discontinuity length is not affected by the beam width. However, this is only true if the discontinuity is longer than the beam width. The measured length of a discontinuity shorter than the beam width will correspond to the beam width itself. For example, the shortest indication that a 5 mm wide beam can measure is 5 mm long. This means that all indications smaller than 5 mm will be oversized and measured as 5 mm.

Focusing Phased Array Probes

Historically, standard phased array probes have been designed with plane elements because of their simplicity and versatility. Some probes that are specially designed for the inspection of smaller diameters feature curved elements (such as concave curvature in elevation probes) to counteract some of the divergence occurring at the part interfaces. However, this curvature value is fixed and therefore not optimized for a wide range of diameters.

Figure 3. Passive-axis focusing wedge.

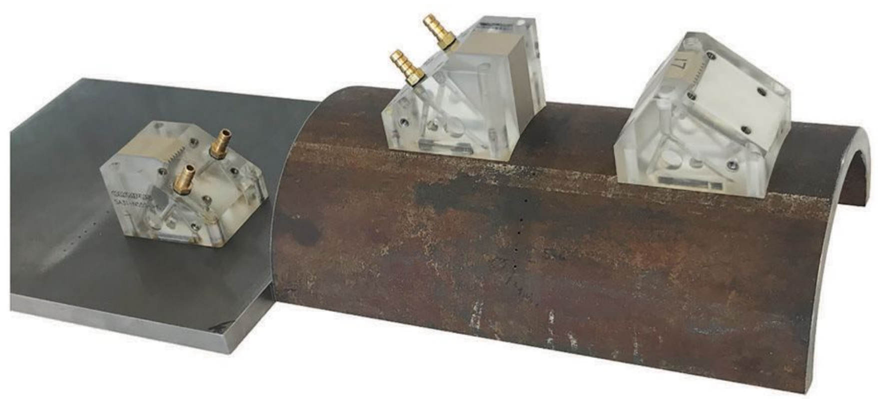

Figure 4. Plate sample with a standard flat wedge (left) and half-pipe sample with a standard wedge (center) and passive-axis focusing wedge (right).

Passive-Axis Focusing Wedges

Wedge technology now exists that enables beam focusing that is optimized for specific pipe diameters. This PAF wedge technology uses two materials of different acoustic velocities, and the interface between the materials is shaped as a converging lens. The goal is to create a beam with a width similar to what is achieved with a flat wedge on a flat surface. PAF wedges used for smaller pipe diameters have smaller lens radiuses for a greater focusing effect, while larger-diameter wedges are fitted with larger lens radiuses. The top surface of the wedge is flat, enabling it to be used with standard probes (Figure 3) (Zhang et al. 2015).

Experimental Results

Two parts were manufactured with 1 mm diameter vertical through-holes separated by different distances. The parts and wedges used are shown in Figure 4. The first part is a plate (on the left), and the second one is a half pipe (on the right) with an outside diameter of 4.5 in. A standard Rexolite wedge with planar bottom face was used to acquire data on the plate, and two other wedges with curved bottom faces matching the half pipe's diameter were used to acquire data on the curved part. One of the curved wedges was a standard Rexolite model, and the other was a PAF composite focusing wedge with a lens radius of 18 mm.

The objective of the experiment was to measure the beam width obtained with the three different wedges using the corner trap reflections of the through-holes on the ID (direct hit) and the OD (second leg) using the 6 dB drop technique.

The same ultrasound setup was used for all three wedges: a linear scan at a 55° refracted angle (natural angle of the wedge) in shear wave with apertures of eight elements using a phased array probe. The probe's active aperture characteristics are as follows:

- 32 elements
- 0.6 mm pitch
- 19.2 mm active area
- 10 mm elevation

Figure 5 shows the relation between the C-scan view, the S-scan view, and the ray-tracing representation. On the left, a schematic from the inspection configuration software shows the lower beams hitting the OD corner trap after a reflection on the back wall and the higher beams hitting the ID corner trap. In the

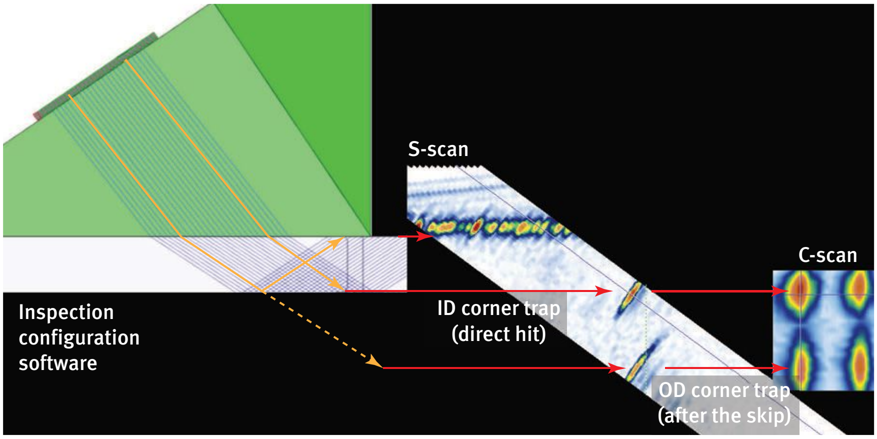

Figure 5. Representation showing the relationship between C-scan, S-scan, and ray-tracing images.

S-scan view (center), the ID corner trap appears higher than the OD corner trap as it arrives earlier in time. On the C-scan view (right), the OD and ID corner traps are represented on top of each other for every through-hole in the scan direction.

This first data set (Figure 6) was acquired with the standard wedge on the flat plate. Although the reflectors are not perfectly uniform, the different corner traps of the seven through-holes are easily identifiable. The amplitude on the ID and OD indications are similar. Using the 6 dB drop technique, the beam width was measured to be 5.0 mm on the ID and 4.1 mm on the OD. The results are summarized in Table 1.

Figure 7 shows the second data set acquired with the standard wedge on the 4.5 in. OD half-pipe sample. The signal amplitude and discontinuity representation in the C-scan view are degraded compared with the previous results. It is difficult to determine the number of distinct indications present in the sample. The beam width was measured to be 5.7 mm on the ID and 7.5 mm on the OD. A beam width of 7.5 mm signifies that all indications would be measured to be at least 7.5 mm long. According to a common code such as ASME B31, which states that the maximum acceptable defect length is 6 or 6.4 mm depending on the code case, all indications detected with this setup would be rejected (ASME 2020).

The third and final scan (Figure 8) was acquired with a PAF wedge on the 4.5 in. OD half-pipe sample. The C-scan view is greatly improved compared with the standard wedge (Figure 8c). Furthermore, the overall image is sharper than the one acquired on the flat plate. The measured beam width was 3.5 mm on the ID and 4.2 mm on the OD.

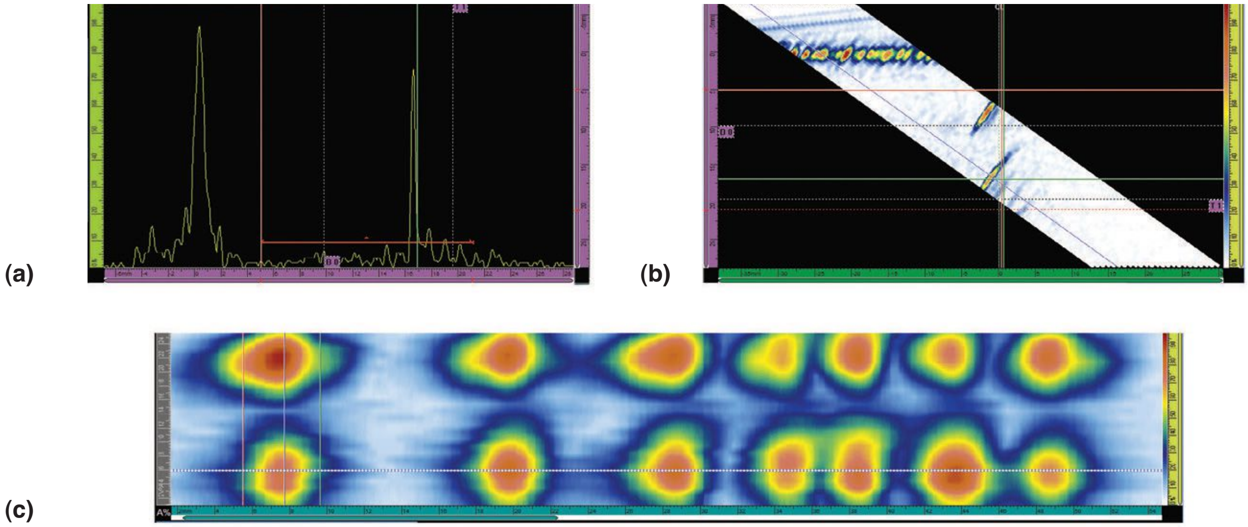

Figure 6. Views of data acquired with a standard wedge on a flat plate: (a) A-scan; (b) S-scan; (c) C-scan.

TABLE 1
Summary of beam width measurements

	ID (mm)	OD (mm)
Standard wedge – plate	5.0	4.1
Standard wedge – pipe	5.7	7.5
PAF wedge series – pipe	3.5	4.2

Conclusions

This experiment demonstrated the negative impact of the part curvature on the length-sizing resolution capability. However, it also showed how the beam divergence caused by the part's external curvature can be compensated for using a PAF wedge with a standard phased array probe. Because of the resulting smaller beam width, this combination of a PAF wedge and phased array probe can enable the measurement of smaller discontinuities and provide sharper images to simplify data interpretation and decrease the rejection rate. ●

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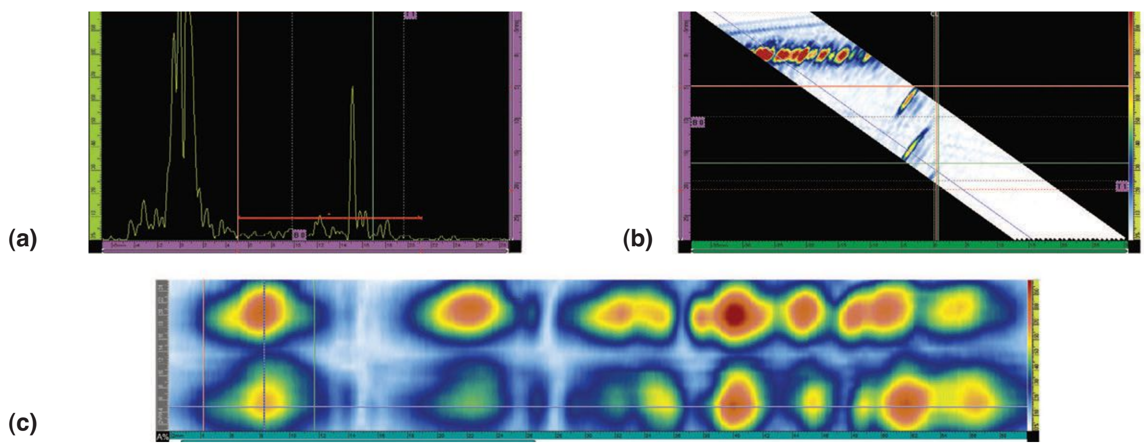

Figure 7. Views of data acquired with a standard wedge on a 4.5 in. (11.43 cm) OD pipe: (a) A-scan; (b) S-scan; (c) C-scan.

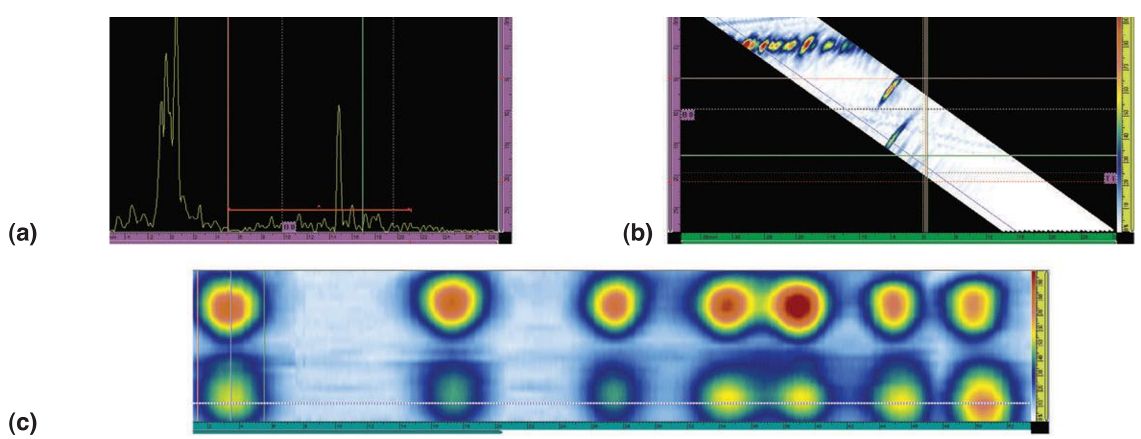

Figure 8. Views of data acquired with a passive-axis focusing wedge on a 4.5 in. (11.43 cm) OD pipe: (a) A-scan; (b) S-scan; (c) C-scan.