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Curved Arrays for Improved Inspection of Small Pipe Welds

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Abstract

This paper describes computer modeling and testing of phased arrays curved in the passive axis to improve focusing on small diameter pipe welds; in practice, a couple of curvatures satisfy most diameter and wall thickness applications. The modeling was followed by experimental testing using one of the curved arrays. Not surprisingly, the curved array showed significant improvements over a flat array on reference notch sizing. One of the major advantages of using curved arrays – as opposed to matrix arrays – is that curving is an economical and simple solution.

Keywords: Phased arrays, curved probes, thin pipes

Introduction

In the past, most small diameter pipe welds were radiographed for defects. However, radiography has significant limitations: safety issues, disruption to work schedules, chemical wastes, and poor detection of planar defects. Manual ultrasonics was permitted by some codes, but suffers from lack of recorded data and dependence on the operator's skills. Automated ultrasonic testing (AUT) has only become commercially viable since the arrival of portable ultrasonic systems [1], and now potentially offers both auditable and reliable results [2].

The arrival of ASME B31.3 Code Cases 179 [3] and 181 [4] has permitted AUT of small diameter pipe girth welds. Code Case 181 in particular needs accurate defect sizing and dimensioning, which is a difficult requirement for small diameter pipe as the ultrasound beam naturally spreads (defocuses) on entry. This will lead to defect oversizing, and hence high reject rates. Phased arrays can focus the beam in an active plane (the axial direction in the pipe), which technically permits better vertical sizing. However, until recently only matrix arrays had the capability of focusing the beam in the horizontal (circumferential) plane, and even their capability is limited.

Matrix and curved arrays offer practical solutions for focusing in both axial and circumferential directions. Curved arrays have been developed previously for larger pipe diameters [5]. Initially, modeling on the small diameter pipes was performed, which showed that only two curvatures were required to cover essentially all small pipe diameters, independent of wall thickness. Matrix arrays did not offer many benefits over curved arrays, and would be more expensive and complex to implement. The larger diameter curved array was manufactured and tested on known reflectors, and compared with a standard flat (unfocused) array.

This paper describes the results of these tests, and shows that curved arrays offer significantly improved sizing in practice. These arrays can be implemented with no extra hardware or software.

Modeling

The PASS (Phased Array Simulation Software) program was used to model the various beams. Three probes were simulated to start:

- Matrix probe: 16x8 elements
- 16-element linear probe with surface curved in passive axis. The radius of curvature is 40 mm
- Flat (unfocused) 16-element linear probe: 5L16-A1 [6].

The modeled results showed that the flat, unfocused beam had significantly worse focusing than either the matrix array or the curved array. There was no obvious advantage in using the matrix probe over a linear array probe with an optimized radius of curvature. This is probably because the curved linear probe is pre-shaped for focusing, whereas the matrix has a flat face and has to use delay laws for the focalization which is less efficient. However, if beam skew ability is required, the matrix array has major advantages.

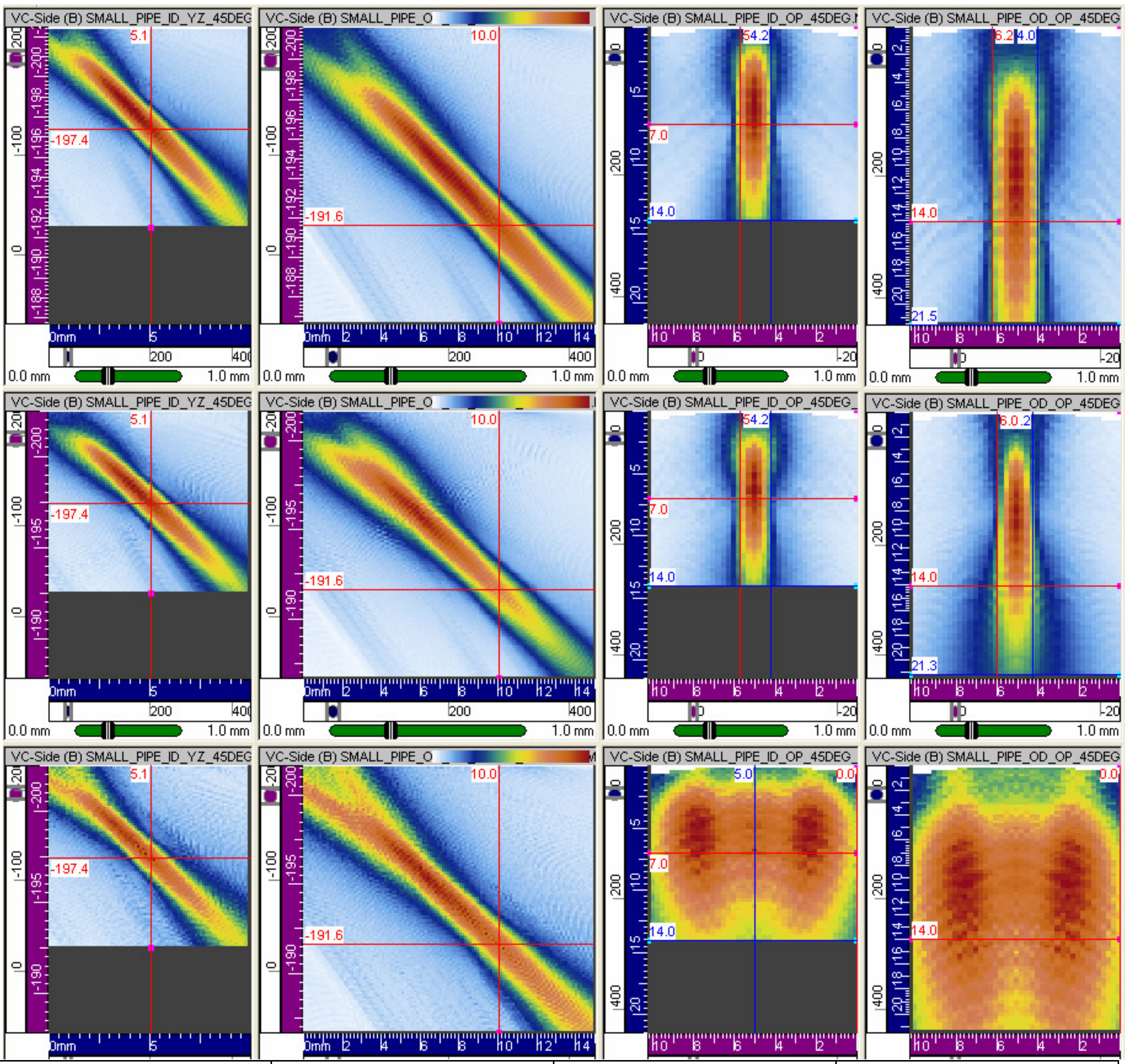
Subsequently, a 10 MHz linear array was modeled for 25, 30, 50, 75mm diameters. By this stage, wall thickness had been demonstrated as relatively unimportant since multiple skips were required for thinner walls, so beam paths tended to be quite constant.

Compared to the flat probe, the curved probe produced a small beam width in the pipe circumferential direction near the beam exit position. This initially reduces the beam divergence from the skips at the pipe ID or OD.

The pipe OD doesn't affect the beam shape much, unless the pipe OD is smaller than 25mm. For this latter case, another probe with a smaller radius of curvature should be used.

In summary, one probe with 40mm radius of curvature is suitable for pipe OD greater than 25mm, and one probe with 30mm of radius of curvature for pipe OD smaller than 25mm. Two curved arrays effectively cover all pipe diameters. Some sample modeling results are shown in Figure 1.

Figure 1: Modeled beam profiles of matrix array (top), curved array (middle) and flat array (bottom) under various parameters.



16x8 matrix. Focal depth 5mm. Field displayed in beam incidence plane	16x8 matrix. Focal depth 10mm. Field displayed in beam incidence plane	16x8 matrix. Focal depth 5mm. Field displayed in beam plane	16x8 matrix. Focal depth 10mm. Field displayed in beam plane
16-element linear probe with radius of curvature of passive axis 22mm. Focal depth 5mm. Field displayed in beam incidence plane	16-element linear probe with radius of curvature of passive axis 22mm. Focal depth 10mm. Field displayed in beam incidence plane.	16-element linear probe with radius of curvature of passive axis 22mm. Focal depth 5mm. Field displayed in beam plane	16-element linear probe with radius of curvature of passive axis 22mm. Focal depth 10mm. Field displayed in beam plane.
16-element flat linear probe 5L16-A1. Focal depth 5mm. Field displayed in beam incidence plane	16-element flat linear probe 5L16-A1. Focal depth 10mm. Field displayed in beam incidence plane.	16-element flat linear probe 5L16-A1. Focal depth 5mm. Field displayed in beam plane	16-element flat linear probe 5L16-A1. Focal depth 10mm. Field displayed in beam plane.

Experimental Results

Two pipes were selected for testing: 2.75" (70 mm) pipe with wall thickness of 6.5mm and a 1.5" (38mm) pipe with wall thickness of 4mm. Note that the 40 mm radius curved array was suitable for pipes from 25 mm to 75 mm. Two wedges were contoured to match the pipe diameters, as per standard practice.

Notches and through-wall holes were scanned with an Olympus NDT OmniScan MX using typical phased array procedures. The same setup was used for the two probes except the gain was reduced for the curved probe. For the 70 mm pipe, the through-hole end on the OD side was detected with one full skip and the through-hole end on the ID side was detected with one and half skips, while the notch was detected with one full skip. For the 38 mm pipe, the through-hole end on the OD side was detected with two full skips and the through-hole end on the ID side was detected with one and half skips. The wedge was kept a fixed distance from the target so that the notch was best seen at about 53^{o} shear wave. The 6dB drop criterion was used for sizing.

The results are summarized in Table 1.

Table 1: Measured dimensions of reference defects.

	70 mm pipe			**38 mm pipe**		
	Apparent size of the 1mm thru-hole at the OD end (mm)	Apparent size of the 1mm thru-hole at the ID end (mm)	Measured length of the notch of 6.9mm in length (mm)	Apparent size of the 1mm thru-hole at the OD end (mm)	Apparent size of the 1mm thru-hole at the ID end (mm)	Measured length of the notch of 6.6mm in length (mm)
Flat 10 MHz array	4.2	4.4	9.6	10	9.8	7.8
Curved 10 MHz array	2.4	3.2	7.1	3.6	2.2	7
Skips	1 skip	1.5 skips	1 skip	2 skips	1.5 skips	2 skips
Note						Split images from non-EDM notch

Discussion

Table 1 shows clearly that curving the array makes a significant improvement in defect sizing. Also, there is minimal cost increase or complexity in using curving arrays, in contrast to using a matrix array.

Although a Rexolite lens was glued to the front face of the curved 10 MHz array, no obvious multiple echoes appear in the signals. Thus, the use of a Rexolite lens is valid.

Since PASS doesn't allow a simulation of the interface skips which are necessary for thin wall pipes, the design of the probe curvature may not be completely optimized for the given pipe diameter range. One solution would be to use more powerful software, e.g. CIVA, to deal with the interface skips.

Conclusions

1. Both modeling and experiments have shown that curving the array for focusing significantly improves the sizing.
2. Modeling shows that matrix arrays offer few advantages over curving the array except beam skewing, and are more complex and expensive.
3. Modeling showed that a couple of curvatures will cover all the diameter-thickness combinations, though only one curved array was tested.
4. As a technology, curved arrays are essentially available now.

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