Dual-Tandem Phased Array Method for Imaging of Near-Vertical Defects in Narrow-Gap Welds

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1. Motivation

Narrow-gap J-groove welds are used in thick section nuclear components to improve welding efficiency. Relative to standard V-grove weld use, the narrow-groove weld geometry can:

- *Reduce required number of weld passes*
- *Reduce weld deposition volume*
- *Reduce heat input*
- *Improve overall welding costs & efficiency*

Narrow grooves typically have weld angles of 2° - 6°, compared to the 40° - 90° observed in V-groove welds, shown in ***Fig. 1***.

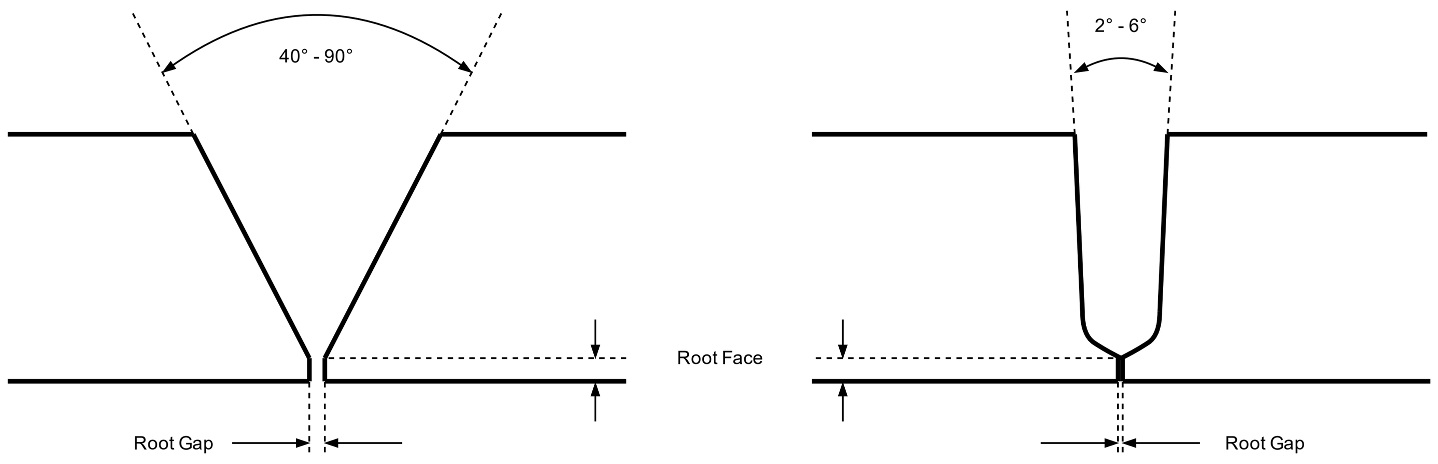

Fig. 1: Comparison of V-groove (left) and narrow J-groove (right) weld geometries

Due to the narrow-groove, Lack-of-Sidewall Fusion (LOSWF) flaws manifest at near-vertical angles, and complicate the inspection procedure required to observe a consistent sensitivity for LOSWF detection.

2. Dual-Tandem Method

By introducing a second opposite facing array on the opposite weld side (see ***Fig. 2***), both pulse-echo and through-weld transmission imaging can be performed. This not only ensures consistent sensitivity to flaw reflections across the weld, but also allows improved sensitivity to diffractive effects.

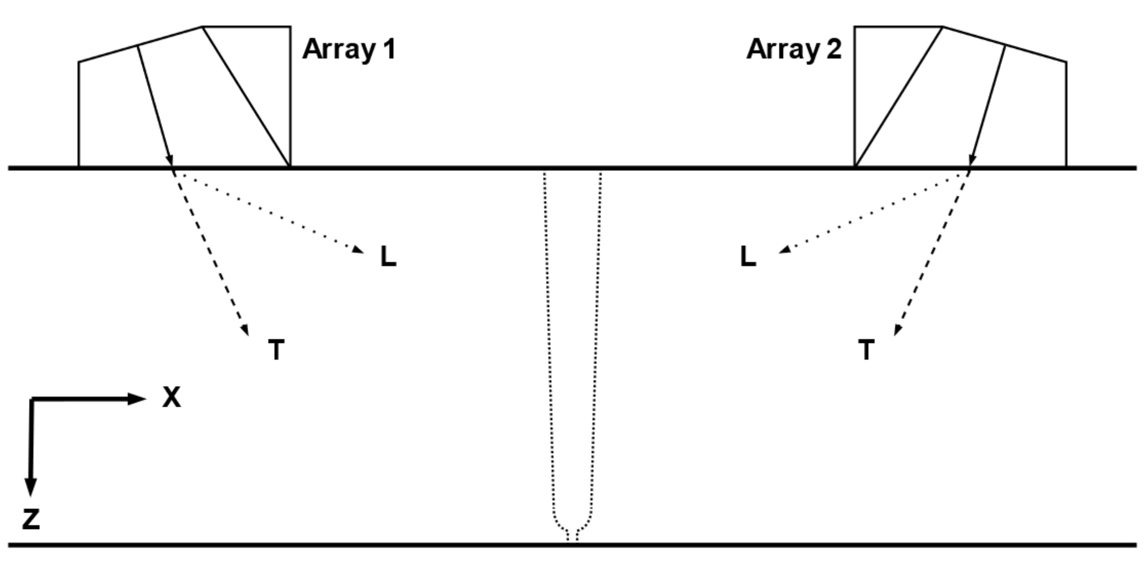

Fig. 2: Dual-tandem phased array method

By treating the system as a single aperture, a Full Matrix Capture (FMC) acquisition allows four unique views of the weld (see ***Fig. 3***):

- *Pulse-echo from right array*
- *Pulse-echo from left array*
- *Through-transmission from left to right array*
- *Through-transmission from right to left array*

A wedge design which allows both longitudinal (**L**) and shear (**T**) transmission expands the number of views available from in a single FMC dataset.

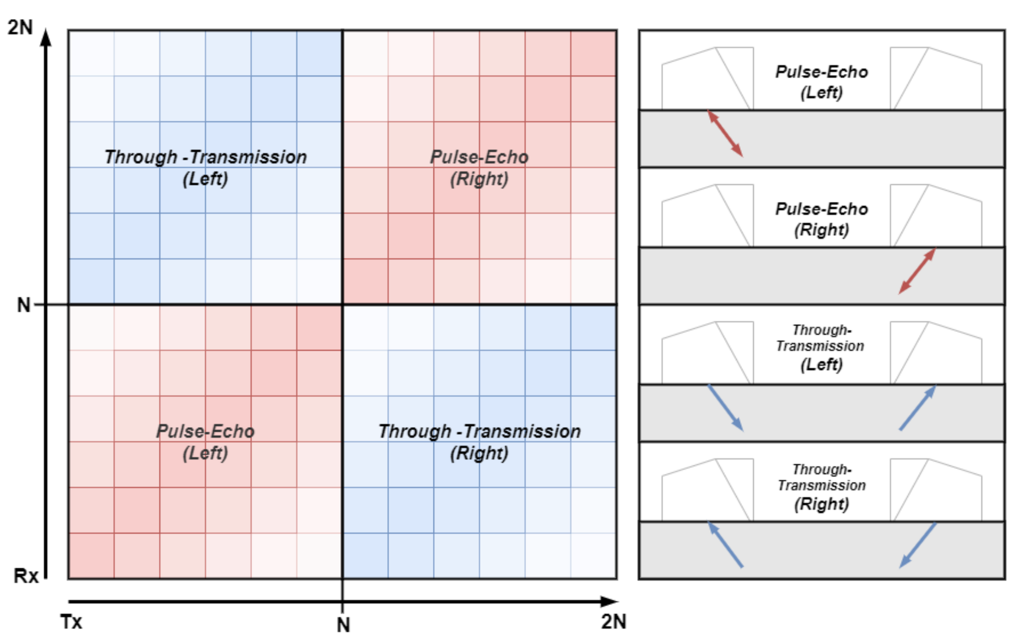

Fig. 3: FMC acquisition method output for two N-element arrays in dual-tandem setup, with four unique views

3. Imaging

By applying the multi-mode Total Focusing Method to each view obtained from the FMC, four unique images can be produced [1].

$$I(x_i, z_j) = \sum_{tx=1}^{N_{tx}} \sum_{rx=1}^{N_{rx}} \hat{u}_{tx,rx}\left(\tau_{tx}(x_i, z_j) + \tau_{rx}(x_i, z_j)\right) \quad (1)$$

An EDM notch was added to a 120.0 mm thick carbon steel block, to mimic a LOSWF defect in a narrow-gap weld. The notch was placed at a depth of 92.5 mm at 2° to the normal, with a size of 5.0 x 1.0 mm.

First considering the pulse-echo view, the multi-mode TFM algorithm [2] produced the images observed in ***Fig. 4***, for the following modes:

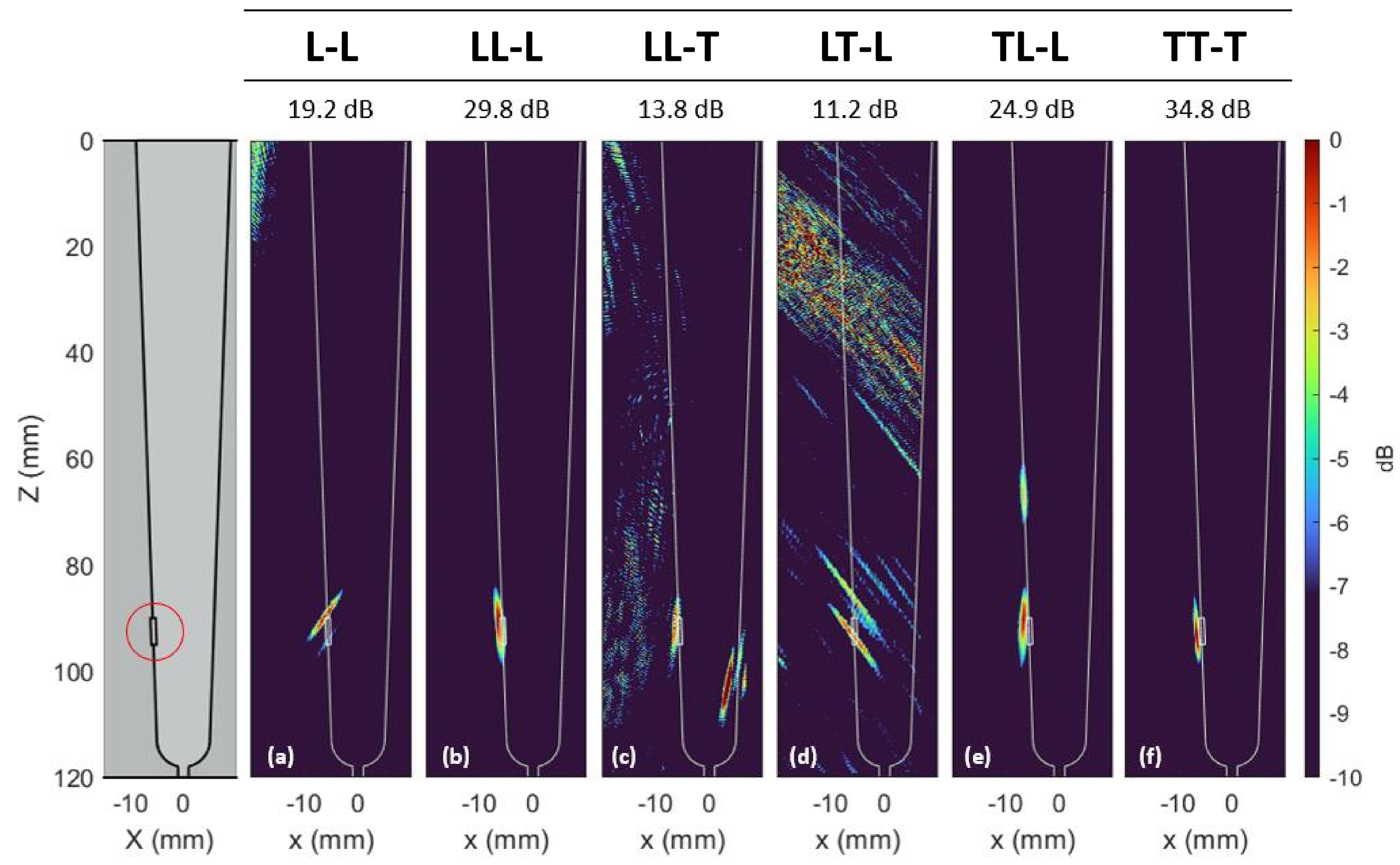

Fig. 4: Pulse-echo TFM images for narrow-gap sample

These exhibited high Signal-to-Noise Ratio (SNR), demonstrating the effectiveness of pulse-echo multi-mode TFM for near-vertical flaws with the dual-tandem method.

Through-transmission imaging was performed using the direct longitudinal mode (L-L), on three similar samples with notches at 27.5 mm, 60.0 mm and 92.5 mm depth (see ***Fig. 5***). This demonstrated high sensitivity to diffractive effects in the samples containing a notch at 60.0 mm and 92.5 mm.

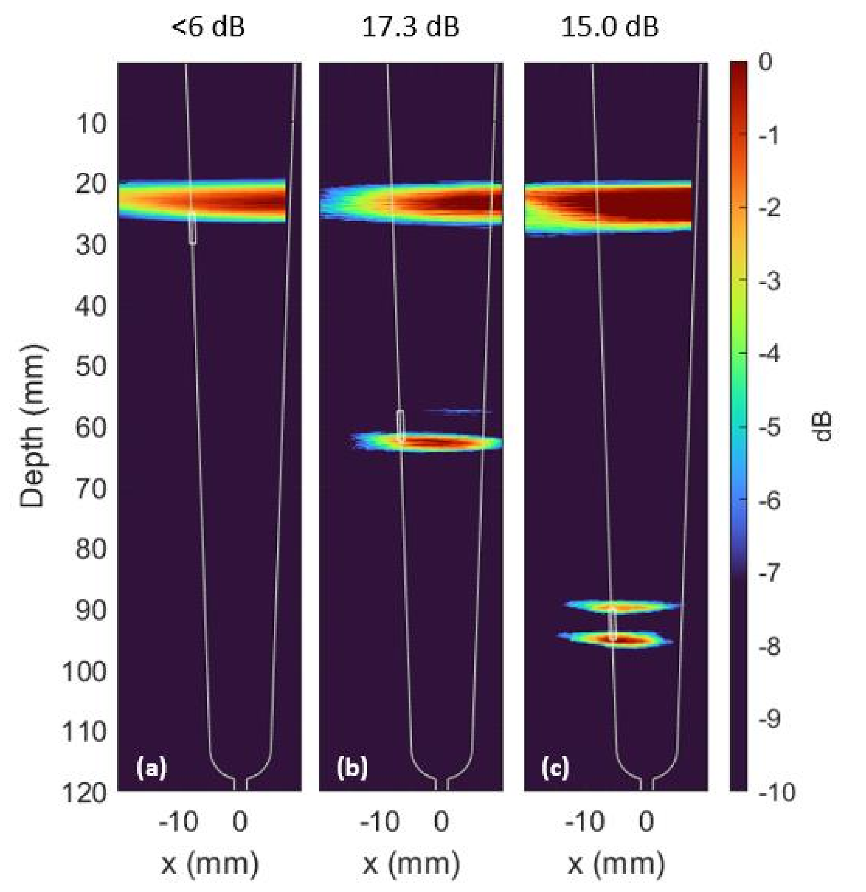

Fig. 5: Through-transmission TFM images using direct longitudinal mode (L-L) on three samples with EDM notches at (a) 27.5 mm, (b) 60.0 mm and (c) 92.5 mm.

4. Conclusion

To conclude, the dual-tandem method has provided high SNR TFM images in both pulse-echo and through-transmission views of near-vertical defects in mock narrow-gap welds.

Future research includes adapting this method to in-process weld inspection, considering temperature gradients, partial weld geometries and high-temperature inspection.

References

[1] Holmes, C., B.W. Drinkwater, and P.D. Wilcox, *Post-processing of the full matrix of ultrasonic transmit–receive array data for non-destructive evaluation.* NDT & E International, 2005. **38**(8): p. 701-711.

[2] Zhang, J., et al., *Defect detection using ultrasonic arrays: The multi-mode total focusing method.* NDT & E International, 2010. **43**(2): p. 123-133.