

Inspection of fastener holes in pitch-catch mode (1/4)

In the aerospace industry, detecting the cracks that sometimes develop around fastener holes is a major issue for aircraft maintenance and life extension. Parts undergoing inspection are usually made of an aluminum alloy and typically have a complex geometry. Their thickness varies from 0.5 to 2 inches. Cracks of concern can be as small as 0.04 inches and can be located anywhere throughout the spar thickness [1].

The conventional inspection technique requires the fastener to be removed. The challenge in developing an easier and less expensive inspection strategy is to design a technique that can be used from the skin side, that does not require removal of the fastener, and that provides the same or better resolution than the conventional method (see Figure 1). The phased-array concept is to use a large linear array in a pseudo-tandem configuration, in which different elements of the same probe are used for transmission and reception [2].

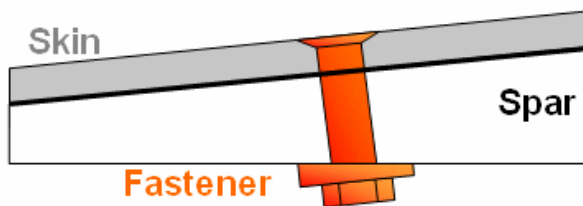


Figure 1: Generic aircraft fastener joining the skin and spar. Large stresses in the fixation area make it a potential site for crack initiation.

The transmitting elements are phased to achieve a focused incident wave along a sectorial scan path after reflection off the bottom surface (see Figure 2). The reception elements are phased to perform a focused sectorial scan (see Figure 3). The convolution between the transmitted and received signals defines the active focal spot for the measurements (see Figure 4). The objective of combining the pitch-catch mode and sectorial scanning in this way is to optimize both the zone coverage and the consistency of the resolution. The optimized inspection strategy uses a 96-element linear array at 5MHz (see animation in Figure 5).

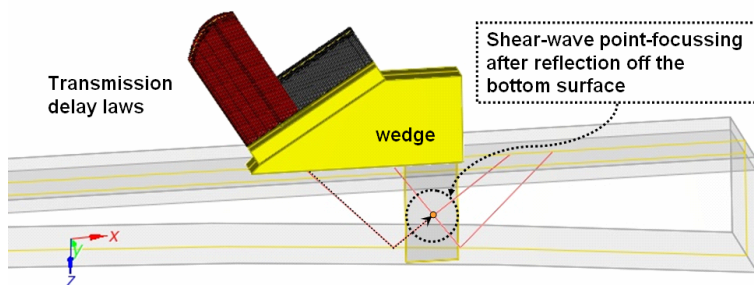


Figure 2: Transmission delay laws are computed to focus shear waves after reflection off the bottom surface.

Advantages:

- Requires only one probe for the complete inspection.
- No dead zones.
- Tunable focusing for transmission and reception.
- Adaptable to any geometry.
- Consistent resolution through the whole thickness.

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The first inspection strategy considered used the same number of elements (40) for both transmission and reception. Simulation results calculated using CIVA (see Figure 6) show good consistency of the focal-spot size throughout the thickness, with a 7dB-amplitude variation between the top and bottom focal spots and a 4mm-diameter focal spot at -6dB. The results also show a lack of resolution underneath the front surface and in reception at the bottom surface.

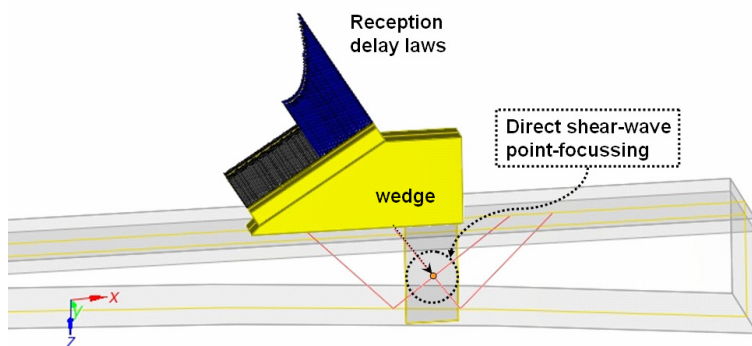


Figure 3: Reception delay laws are computed to focus shear waves directly beneath the probe wedge.

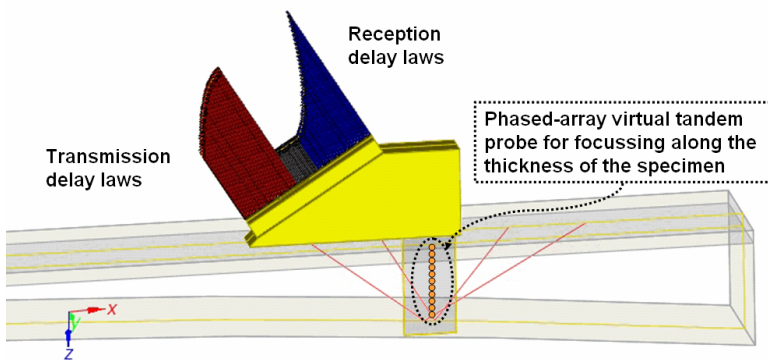


Figure 4: Resolved focal points using separate transmission and reception delay laws. The entire thickness is covered by the inspection procedure. The linear array replaces a large number of tandem probes (one for each thickness).

Using these results, a new strategy was designed that uses 54 elements for transmission and 42 elements for reception. The elements are phased in both transmission and reception to improve resolution. Results (see Figures 7, 8 and 9) show better resolution throughout the entire thickness (2mm-diameter focal spot at -6dB), as well as better consistency (2.5 dB variation from top to bottom). The linear array replaces a large number of tandem probes (one for each thickness).

Inspection of fastener holes in pitch-catch mode (3/4)

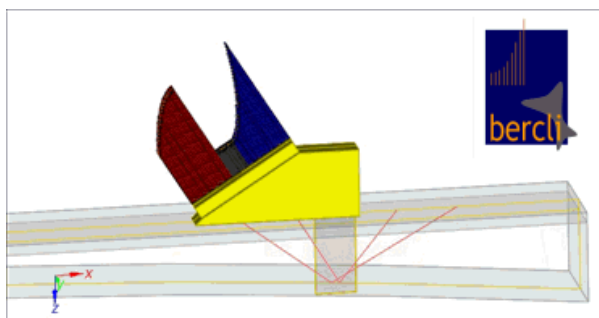


Figure 5: Ray tracing of the focal points using separate transmission and reception delay laws. The entire thickness of the part is covered by the inspection procedure.

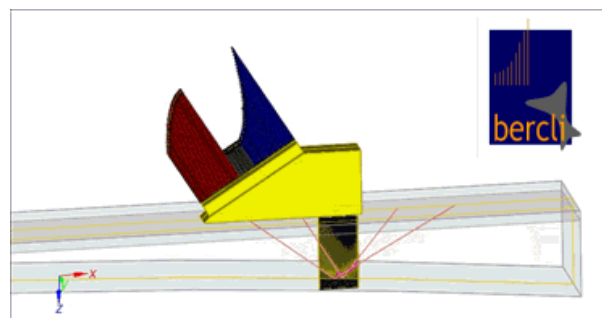


Figure 6: 40-element configuration. Beam visualization shows sufficient resolution for crack detection.

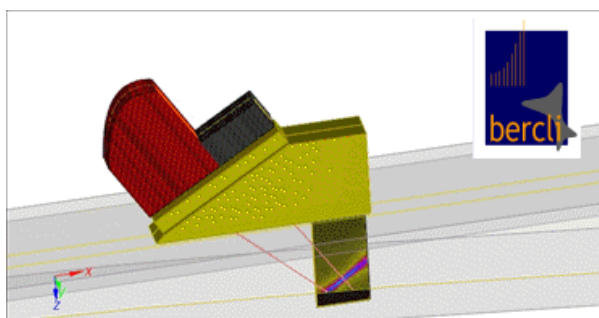


Figure 7: Visualization of the focused beam after reflection off the bottom surface using 54 elements for transmission.

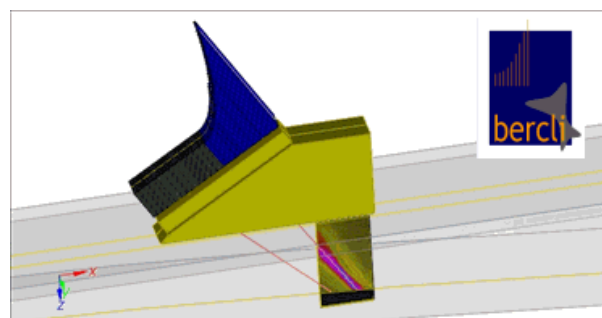


Figure 8: Visualization of the focused beam using 42 elements for reception.

Inspection of fastener holes in pitch-catch mode (4/4)

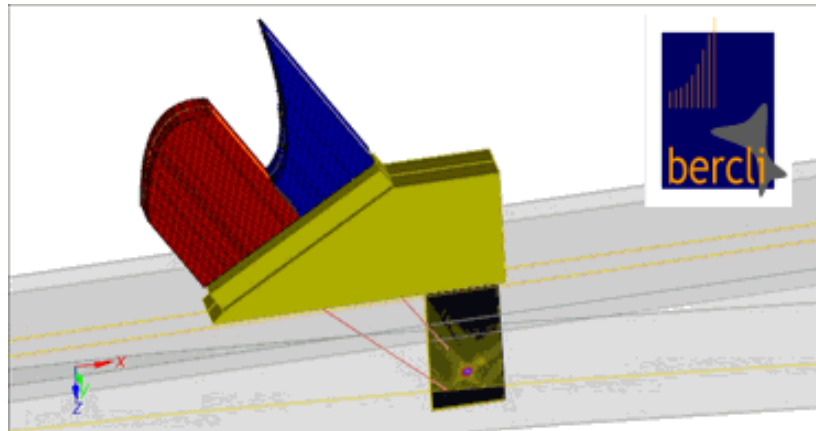


Figure 9: The convolution of the transmitted and received beams gives the effective focal spot size for defect detection.

[1] Neau G., Hopkins D., Tretout H, and Boyer L., "Phased-array applications for aircraft maintenance, manufacturing and development", Aerospace Testing Expo 2006, UKIP Media & Events 2006.

[2] Mahaut S., Chatillon S., Raillon-Picot R. and Calmon P., "Simulation and application of dynamic inspection modes using ultrasonic phased arrays", Review of Quantitative Nondestructive Evaluation Vol. 23, ed. by D. O. Thompson and D. E. Chimenti, American Institute of Physics, 2004.