Technologies Used to Inspect Composite Materials

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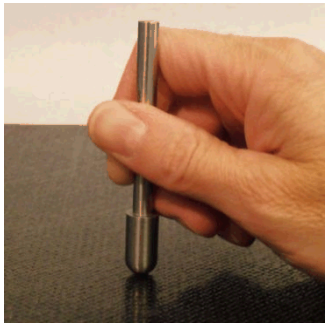
Introduction

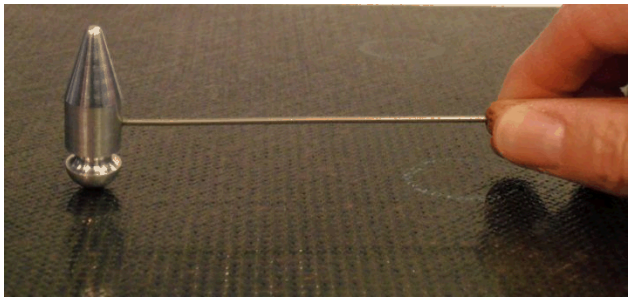
- Adhesive-bonded and composite components and structures have become an important part of aircraft manufacturing over the last 35 years.
- Quality and reliable is extremely important to the integrity of composite structures throughout their service life.
- The wide range of materials and configurations used in composite structures and the need for nondestructive evaluation of bonds has resulted in many different types of testing equipment and methods being used.

Bond Testing History

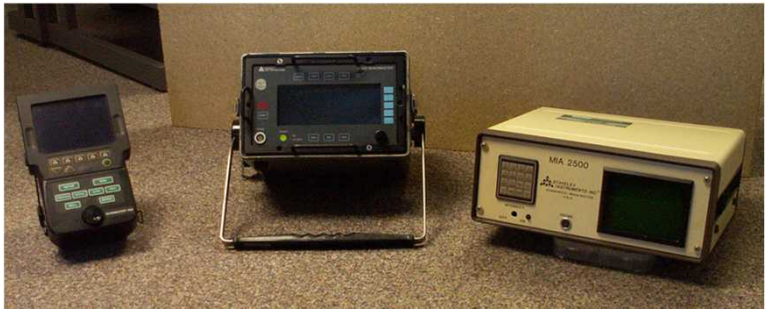
- Perhaps the earliest form of bond testing is the coin tap method.

- Coin tap was followed by the tap hammer method.





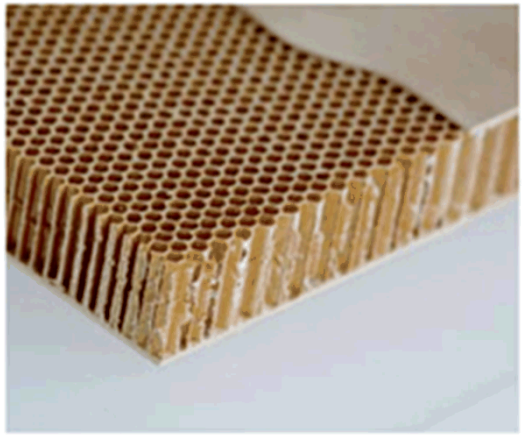
- Mechanical taps were replaced by early electronic instruments



Overview of Composites

Composites are made up of two or more materials with distinct properties and combined into a heterogeneous mixture. The mixture benefits from mechanical properties not found within the individual properties. Composites can involve ceramics, wood and/or polymers.

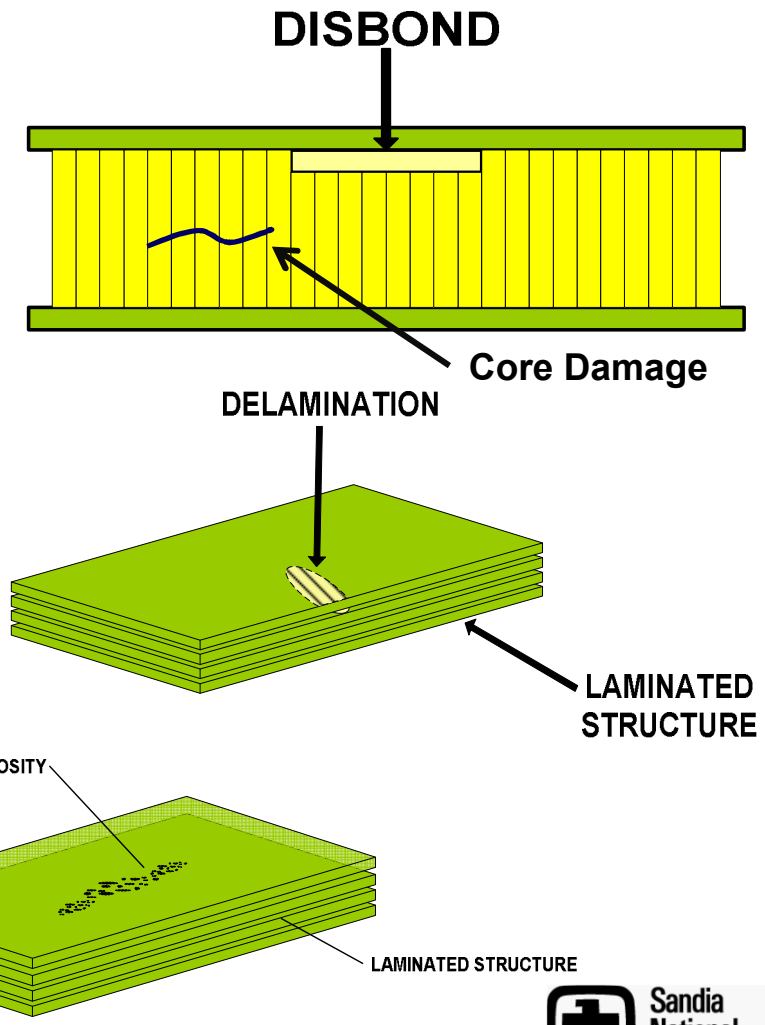
- Different material types can be used for the skin:
  - Aluminum
  - Fiberglass
  - Graphite (Carbon)
  - Hybrid
  - Kevlar (DuPont TM)



- The core that is used in composite component structures comes in different material type and densities:
  - Aluminum
  - Fiberglass
  - Nomex

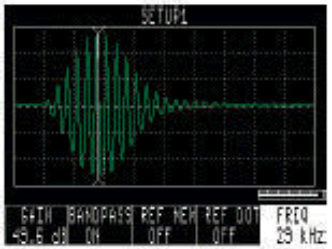
Overview of Composites

- Generally four types of flaws in composite materials:
  - Disbond
  - Core Damage
  - Delamination
  - Porosity
- These flaws can occur do to the following:
  - Impact damage
  - Lighting Strike (heat damage)
  - Manufactures Defect

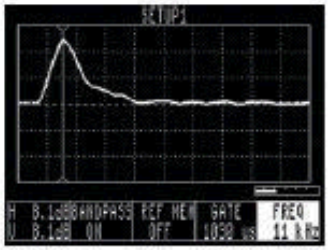


Bond Testing Technology

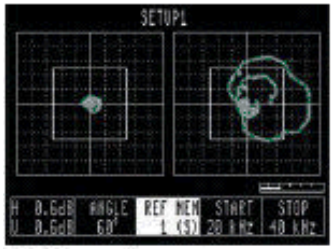
- There are three test modes and five inspection methods available with most equipment.
- The optimum method would be selected using a test standard that represents both bond and disbond conditions based on the construction of the component.



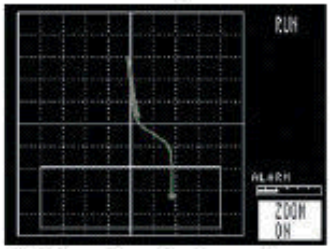
Pitch-catch RF



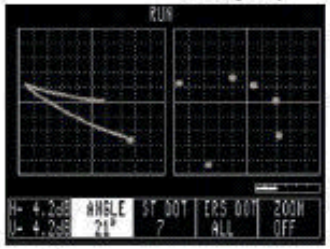
Pitch-catch impulse



Pitch-catch swept



MIA (mechanical impedance analysis)



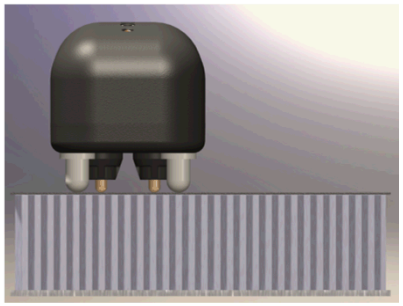
Resonance

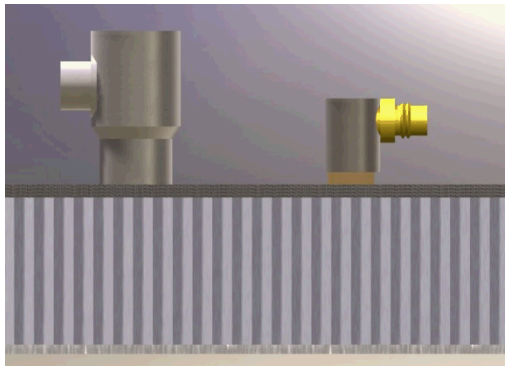
Overview

- Bond testing (BT) can be used to test a array of bonded and composite materials used in a variety structures. There are similarities and differences when comparing to traditional ultrasonic flaw detectors. Bond equipment uses sound waves however, unlike ultrasonic testing (UT) it does not use reflected ultrasound energy. In UT, sound is coupled into a material and then echoes are detected to determine if flaws are present or material thickness.

- Bond testing Pitch-Catch & MIA, uses changes in plate-waves / flexural and compression waves that result from a good bond compared to areas that are not bonded well, or where there may be a disbond or delamination within a structure.

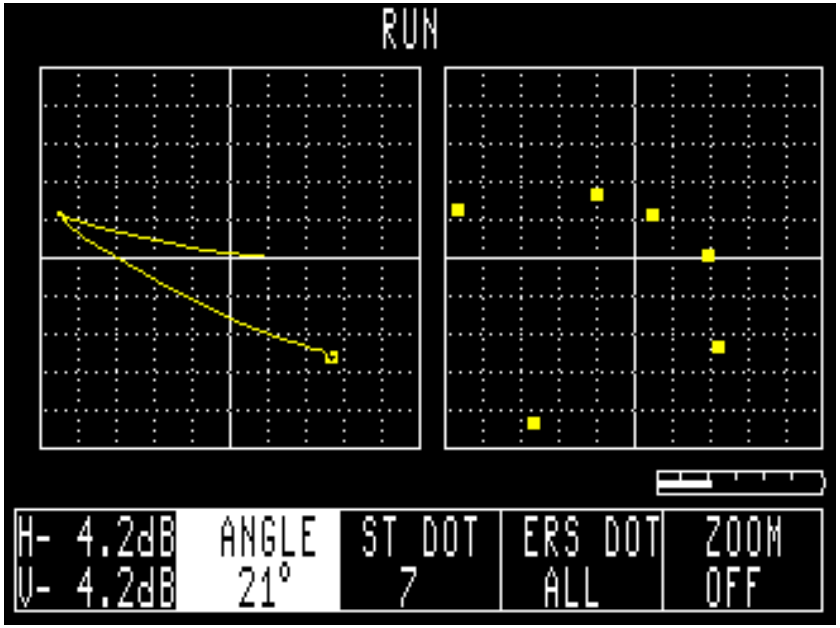
- Bond testing Resonance, does not use sound propagation velocity or reflected sound, but only changes in phase and amplitude of the propagating / standing wave measured within a component.





Resonance Mode

- Resonance method is very similar to an ultrasonic A-scan pulse echo inspection with couplant included, it is based on changes in phase and amplitude in probe resonance.
- Resonance method uses special a narrow bandwidth contact Sonic probes. The test is based on the change in the impedance of the resonant- Q - acoustically coupled to a material.
- The impedance change in the crystal are analyzed to detect changes within the part being tested.



Resonance Mode: typical application

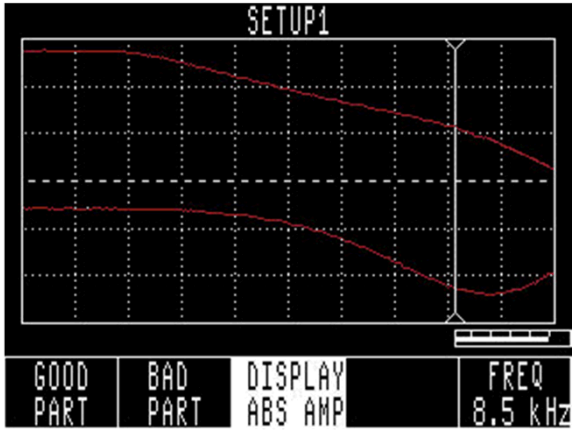
- Resonance is generally used for detecting skin-to-skin disbonds such as aluminum lap joints. This mode also works well for inter-ply delamination in composite structures. In many cases the depth of delamination's can be estimated using the signal-phase rotation.

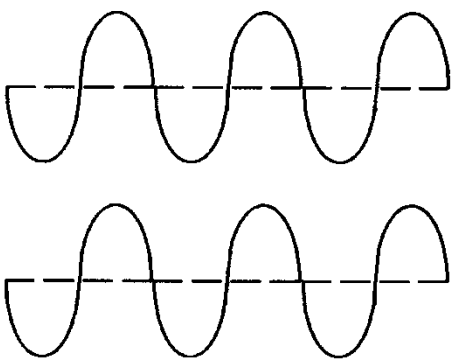
250KHz resonance probe used on an aircraft lap splice joint to detect corrosion between the lap splice skins

MIA Mode

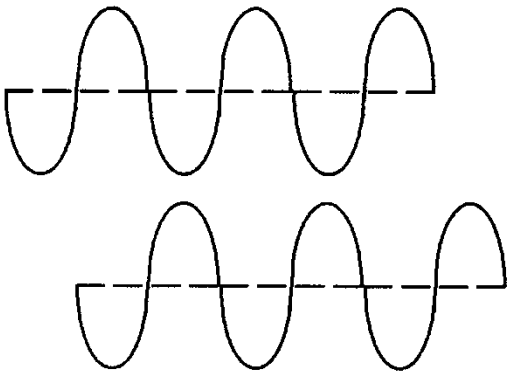
Mechanical Impedance Analysis operates without couplant and is usually spring loaded, it is based on measuring the stiffness and mass of the material under test.

When the transmit and receive elements are nulled, they vibrate together at the same phase and amplitude. When the probe is placed on a structure, the receiving element is affected by the sample stiffness, which varies from bonded to disbonded conditions. This change is monitored as a comparison between the transmit and receive phase and amplitude signals. The next figure shows a difference in phase.





Transmit and receive elements are nulled and in phase.



Transmit and receive elements are in contact with a test part and are 180 degrees out of phase.

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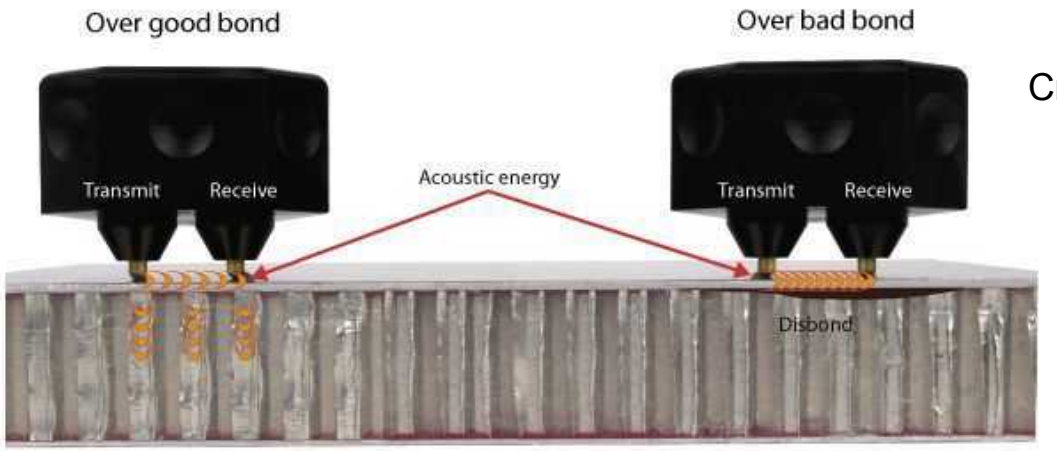
MIA Mode: typical application

- MIA probes have a point-contact area suitable for use on irregular or curved surfaces. The MIA method works well to detect disbonds and crushed core conditions.

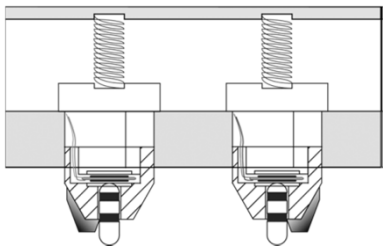
S-MP-5 probe being used on a rear wing end plate from a Formula 1 race car, the construction is carbon fiber skins with Rohacell foam core and Nomex core. This inspection is used to detect near surface skin to core disbond.

Pitch-Catch Test Mode

- The pitch-catch mode is very easy in terms of calibration and requires no couplant.
- One element transmits (pitches) a burst of acoustic energy into the test part and a separate element receives (catches) the plate-waves / flexural propagated across the test piece as shown.
- The plate-waves / flexural motion are propagated into the test piece. Disbonds and delamination's change the stiffness of the part. The return signals are detected and a phase-amplitude display is used to show the effect of good and bad bonds on the sound path.



Cross-sectional view of a typical pitch-catch probe.



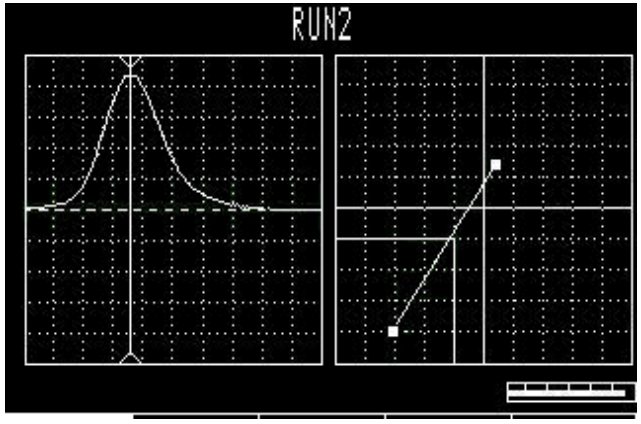
Pitch-Catch Mode

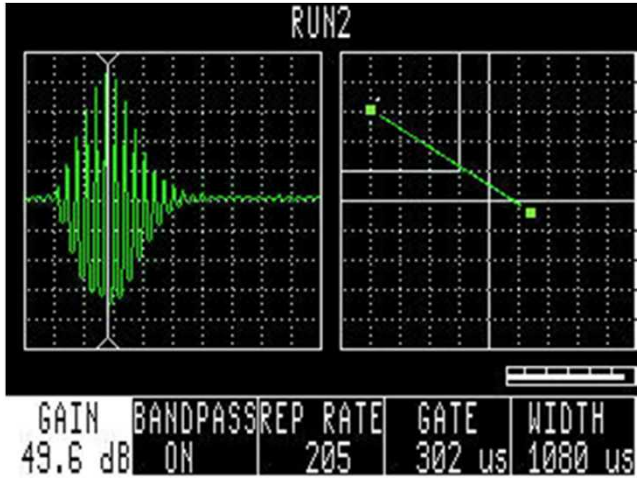
Impulse & RF Method

- The pitch-catch Impulse and RF methods utilize a repeated burst of a single frequency . The frequency is selected to provide the maximum plate / flexural motion within the component under test.

- A variable time gate is used to select the received pulse that has the greatest change in amplitude when the probe is scanned from a bonded area to a disbonded area.

- The user positions a time gate at the optimum point to monitor the response of the receive signal most affected by disbonds. This optimizes the data displayed by the flying dot on the RUN display.



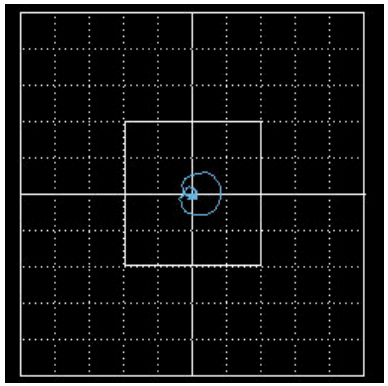


Pitch-Catch Mode

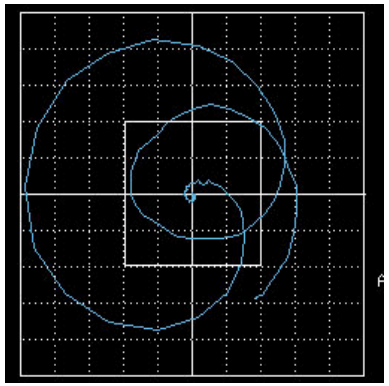
Swept Method

- For the pitch-catch swept method, one element sweeps through multiple frequencies defined by the operator. The swept frequency (5KHz – 100KHz) provides a circular display.

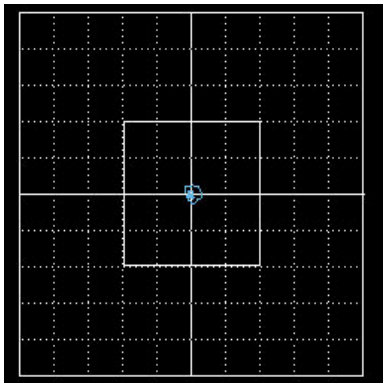
- The swept signals are monitored and processed by the second element. The return signals are detected and a phase vs. amplitude display is used to show the effects of good bond compared to the disbond areas along the plate wave path.



Bond

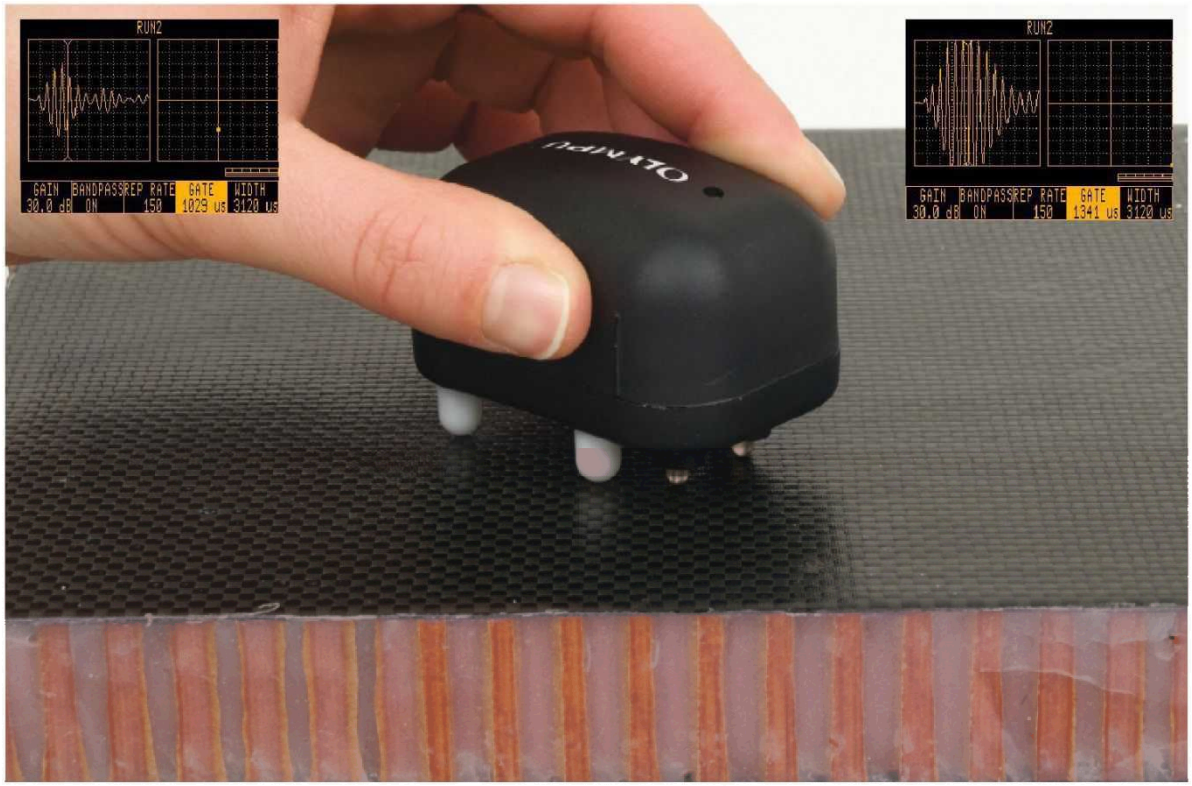


Disbond



No contact

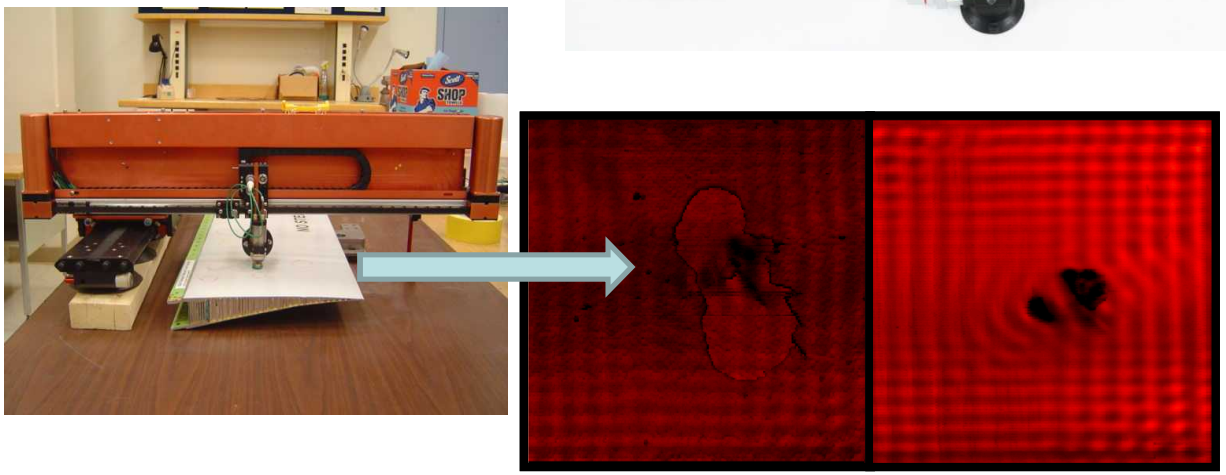
Pitch-Catch Test Mode



S-PC-P14 pitch catch probe used on a carbon fiber skin / Nomex cored structure to detect near-side and far side skin to core disbonds.

Bond Testing with Scanners

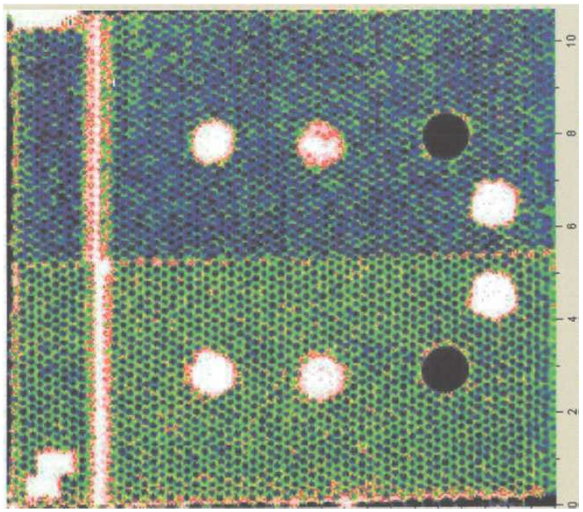
Vendors are now offering systems with scanning capabilities. This allows users to use their existing probes and create C-Scanning images.



Mechanical Impedance Analysis

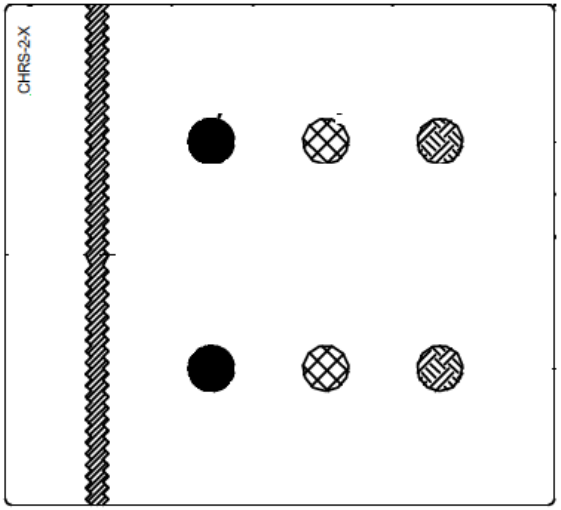
Pitch-Catch Inspection Data

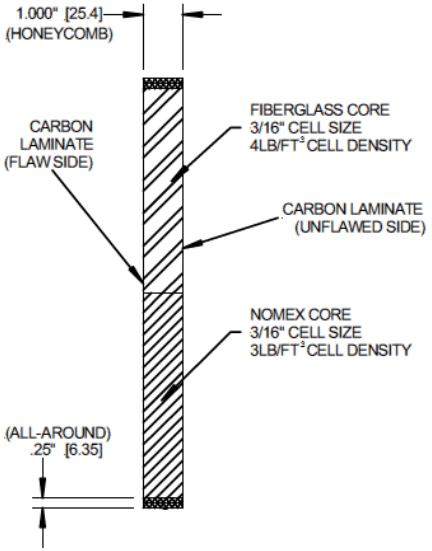
TTU C-scan image



- Pitch-Catch is of the most commonly used test method for skin to core disbonds.

- Test standard CFRP honeycomb sandwich. ARP 5606 CHRS-2-6, also listed in some NTM procedures.





CORE MACHINED TO MAKE SKIN–TO–CORE DISBOND

INSERTS BETWEEN PLIES TO MAKE DELAMINATIONS

POTTED CORE

CORE SPLICE

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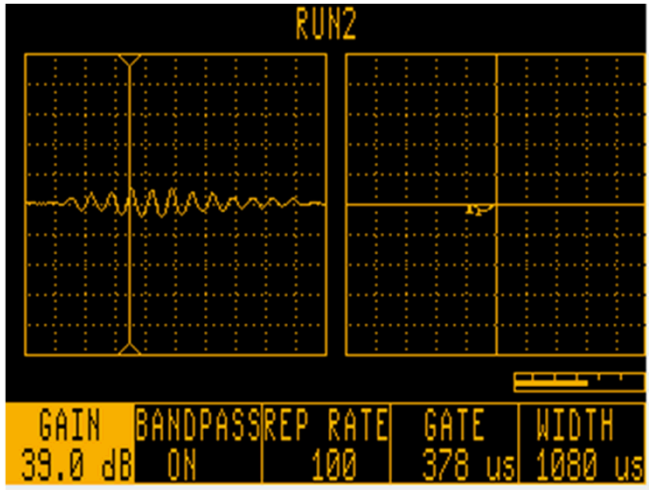
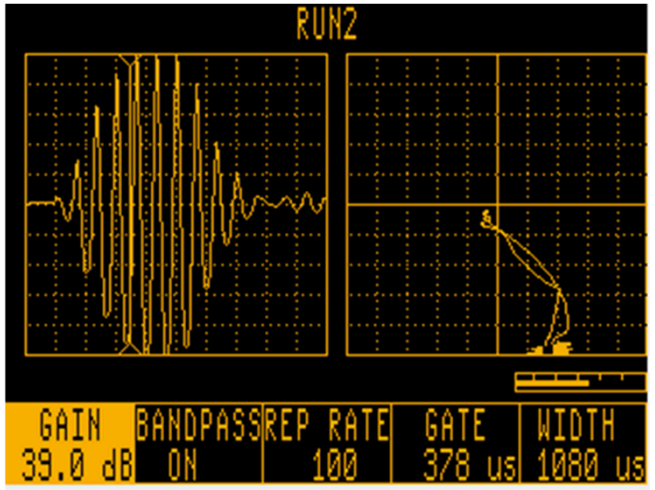
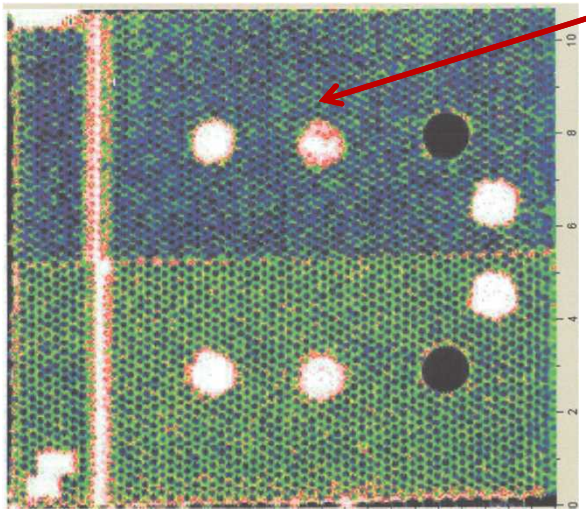
Pitch-Catch Inspection Data (continued)

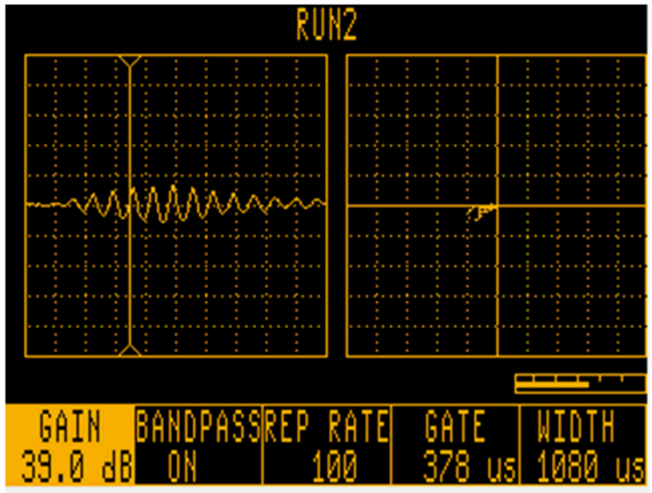


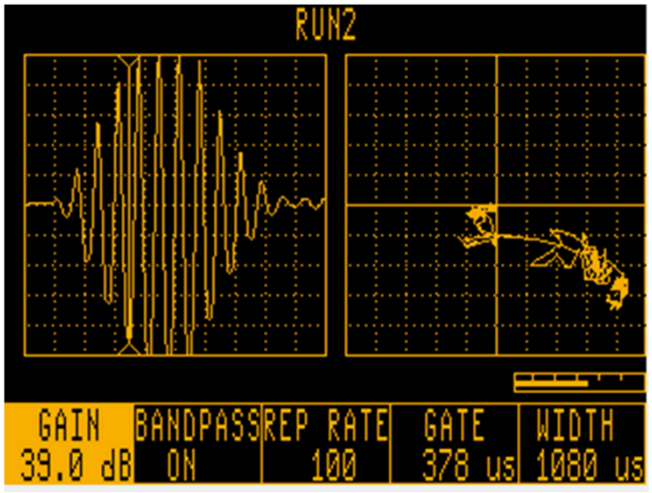


CHRS-2-6 Fiberglass core, test results at 14Khz looking at nearside disbonds.

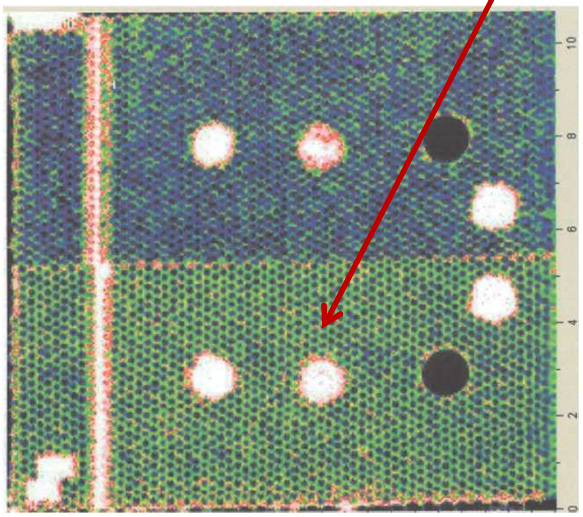


Pitch-Catch Inspection Data (continued)



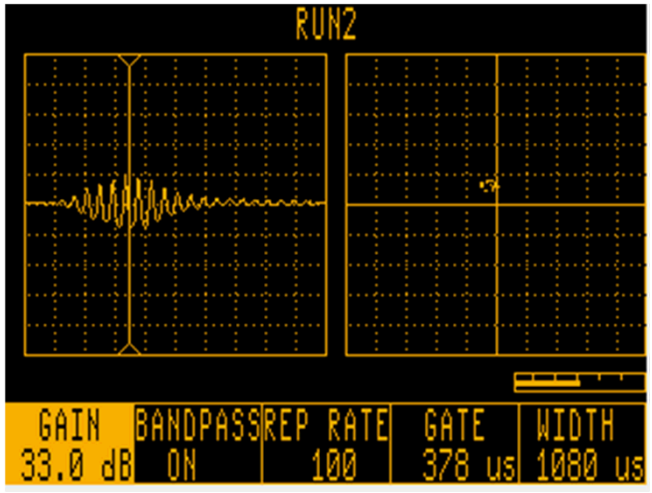


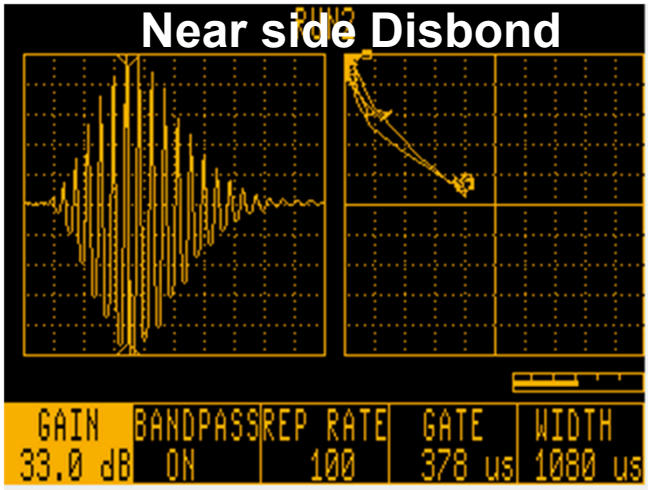
CHRS-2-6 Nomex core, results at 14Khz Testing looking at nearside disbonds

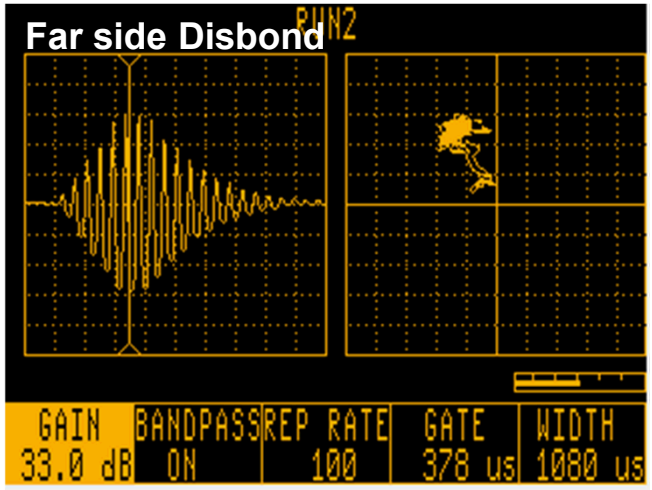


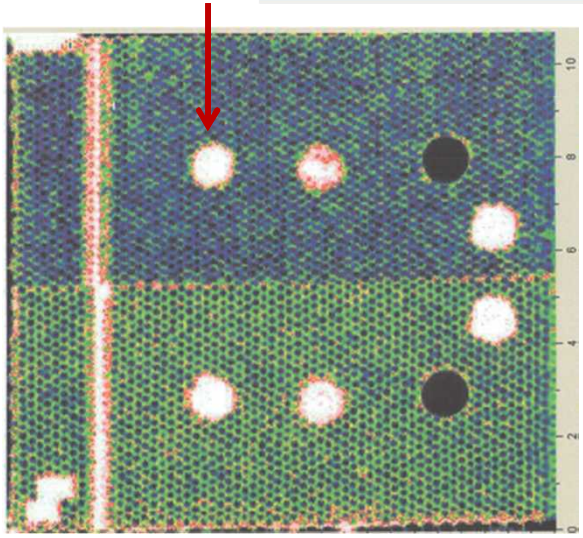
Pitch-Catch Inspection Data (continued)

CHRS-2-6 Fiberglass core; at 22KHz, best results for near and far side disbond.









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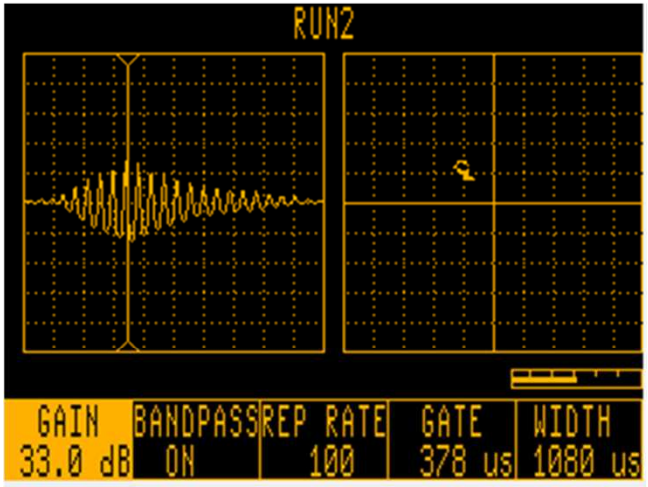
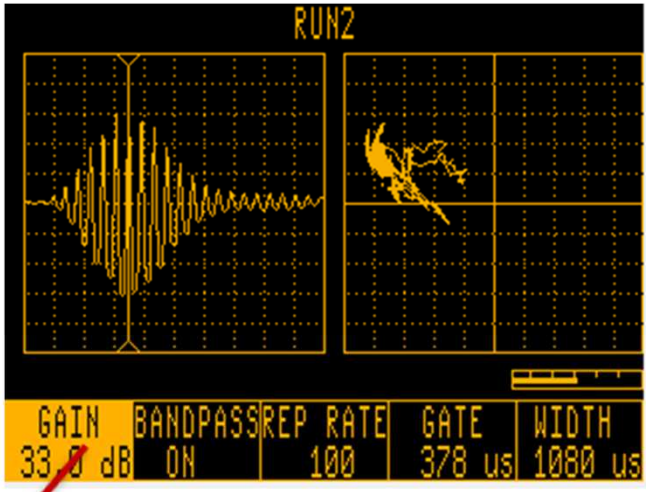
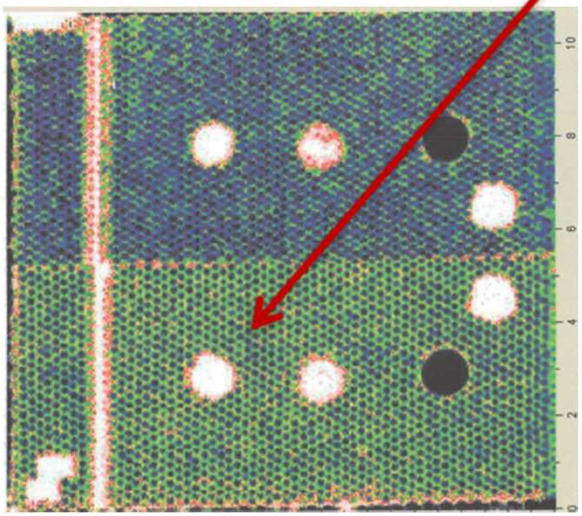
Pitch-Catch Inspection Data (continued)

CHRS-2-6 Fiberglass core good results at 22KHz Testing looking at far side disbond





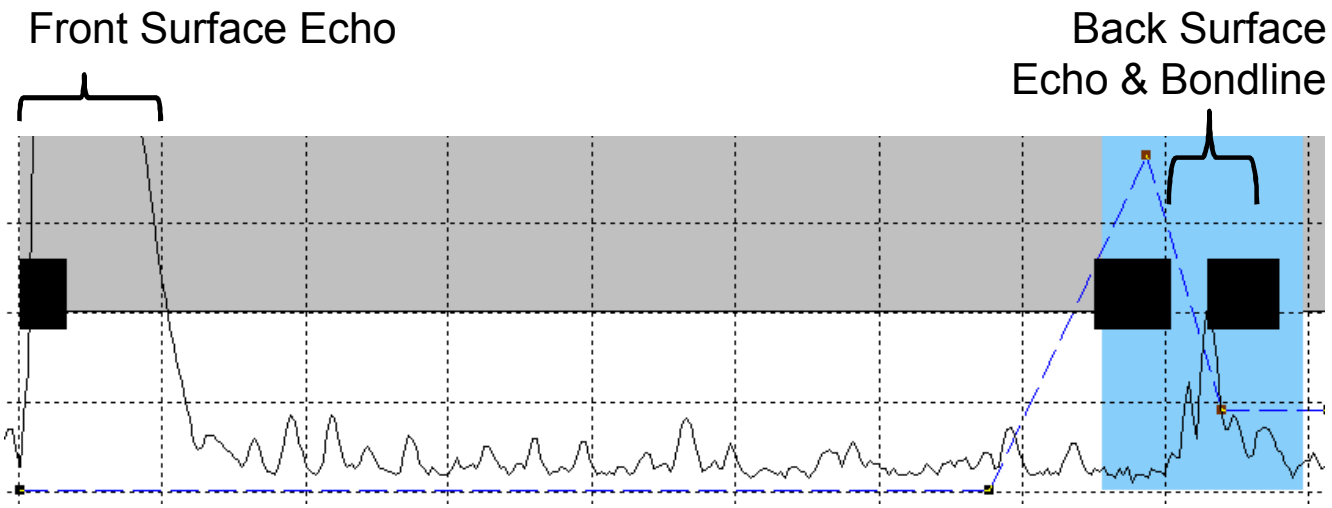


Ultrasonic Inspection

Ultrasonic transducers transmit sonic waves into a sample and measure the reflected responses.

Near surface resolution can be improved with a delay line tip, to provide a time delay between sound generation and reception of reflected energy.

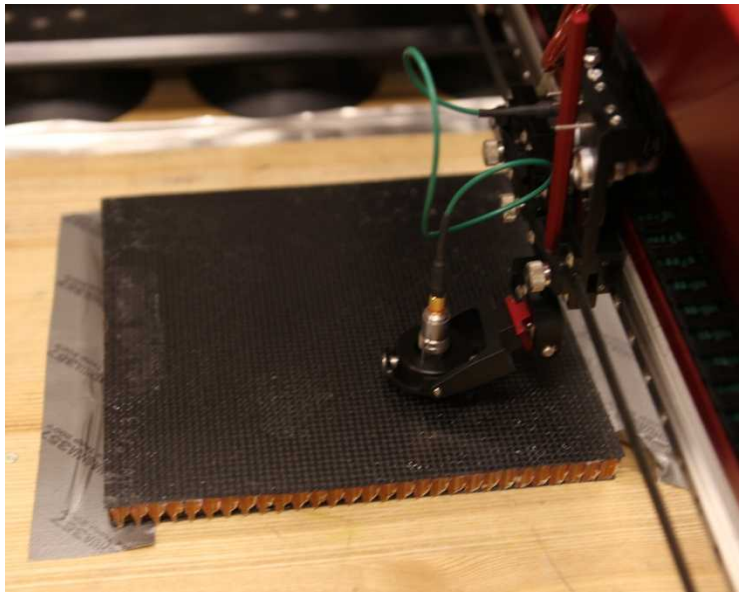
Low-frequency Resonant, Ultrasonic Transducers transmit ultrasonic waves that penetrate through the laminate and enter the honeycomb cell wall at the node bond adhesive interface.



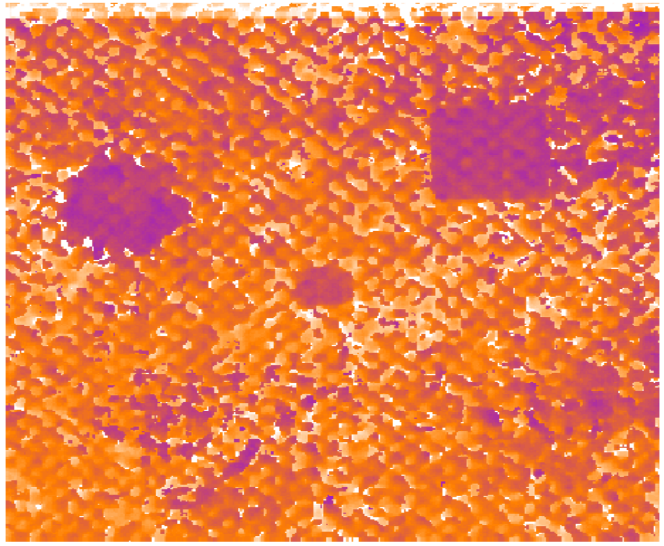
Ultrasonic (UT) Inspection Results

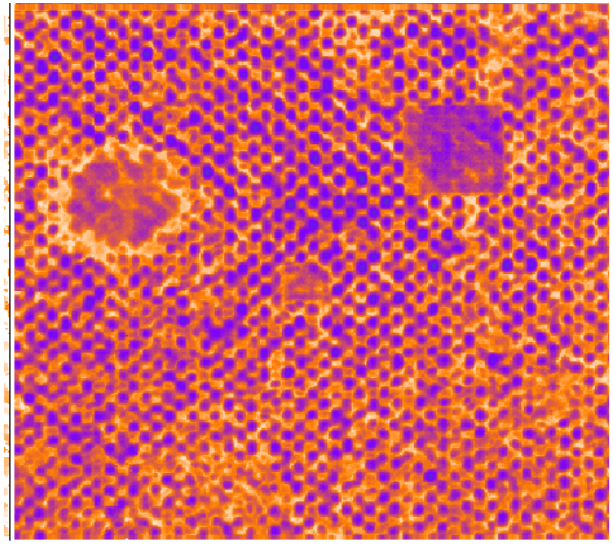
The Composite Sample was UT inspected using the below equipment and setup,

- MAUS V™, (Mobile automated UT scanner) was used to acquire the images.
- A 5 MHz probe, 6.35 mm in diameter.
- Scanner resolution- 0.5 mm.
- The gate was set to monitor the backwall signal from the laminate.



Amplitude Gate Image





Depth Gate Image

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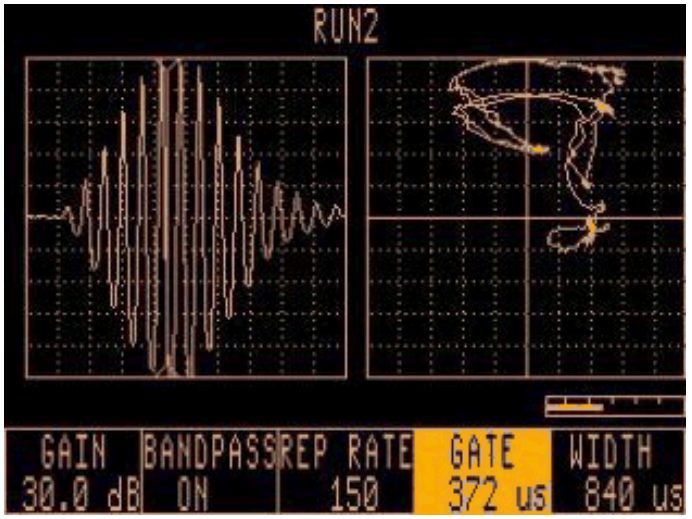
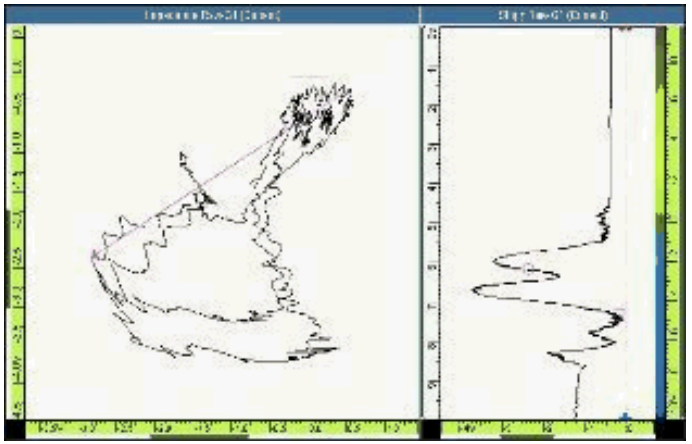
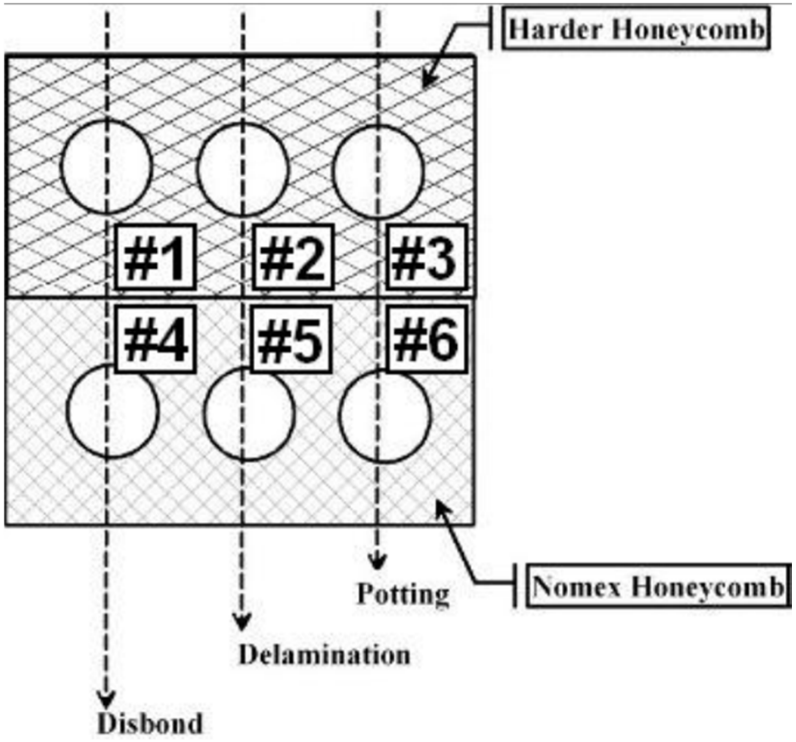
Bond Testing Advancements

- Impedance plane representation is similar handheld devices. Both techniques use RF impedance plane (phase angle inversion).
- Up to 8 simultaneous frequencies
- C-scan generated from the vertical amplitude of the impedance plane (vertical strip chart)
- Tested with probe S-PC-P13L pitch-catch probe





Tests standards (honeycomb sandwich)

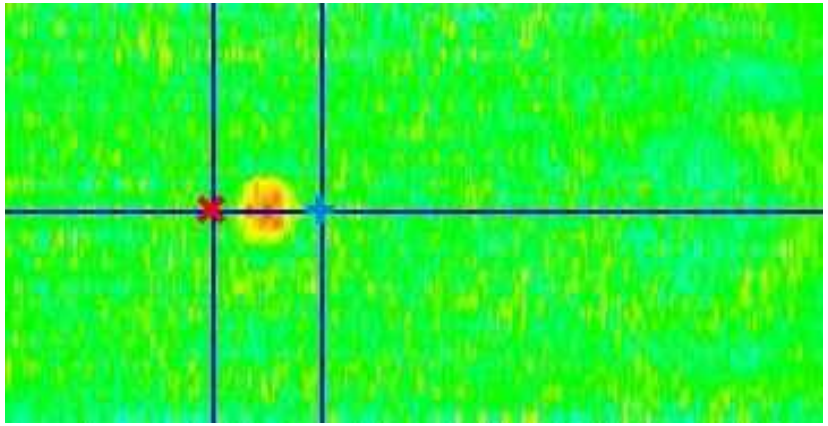


CHRS-1-3, CHRS-1-6, CHRS-1-9 and CHRS-1-12 samples: composite, 306 mm x 280 mm. 3 to 12 plies, 1 in thick honeycomb

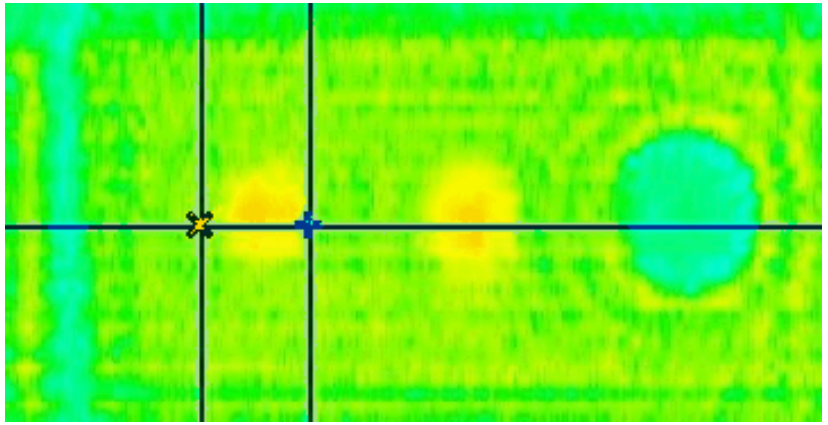
Observations

Defect detection in function of frequency

CHRS-1-6 at 8 kHz (only disbond is detected)



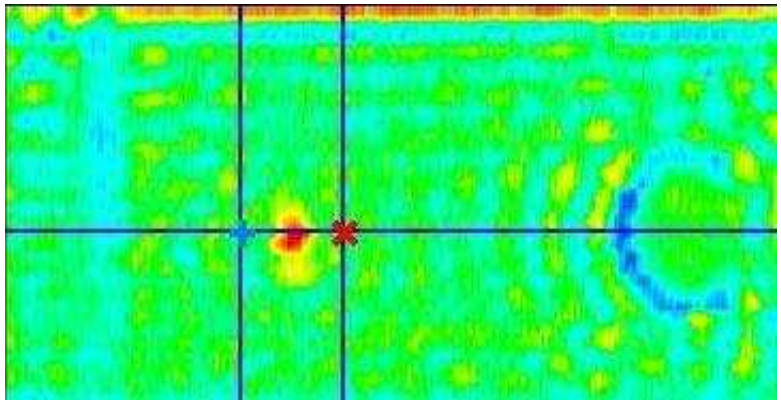
CHRS-1-6 at 20 kHz (disbond, delamination and potting detected)



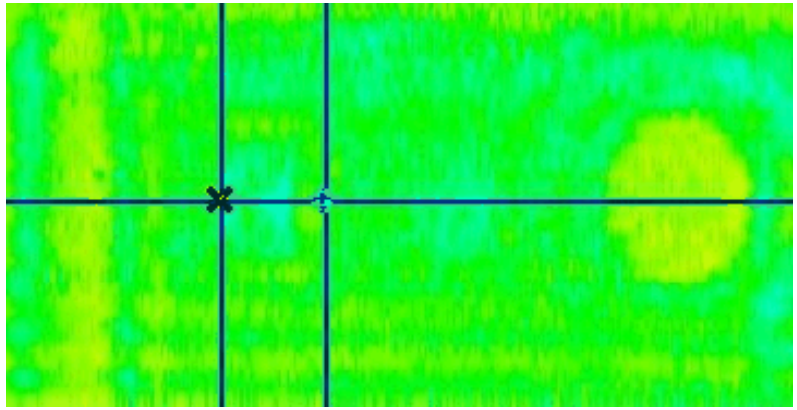
Observations

Defect detection in function of frequency

CHRS-1-6 far-side at 18 kHz (disbond)

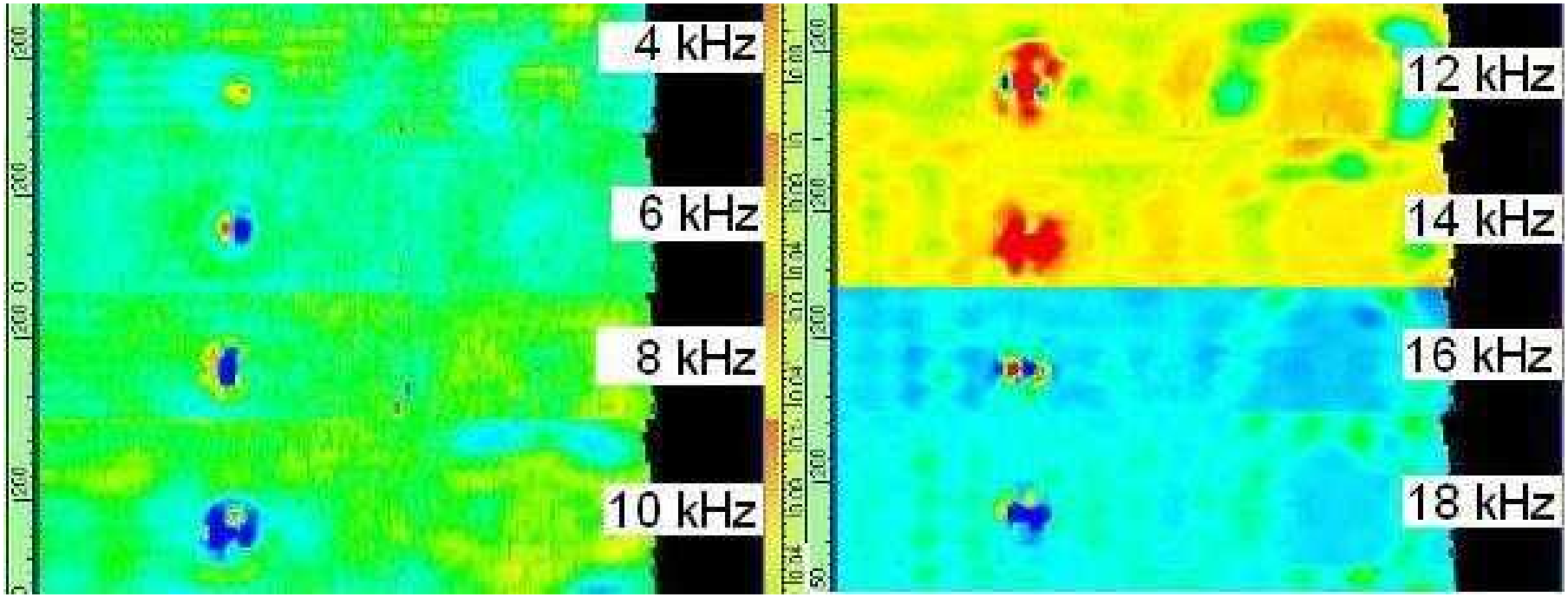


CHRS-1-6 at 14 kHz, very poor disbond detection



Observations

Variation of defect shape in function of frequency and position of the probe at frequency smaller than 20 KHz.

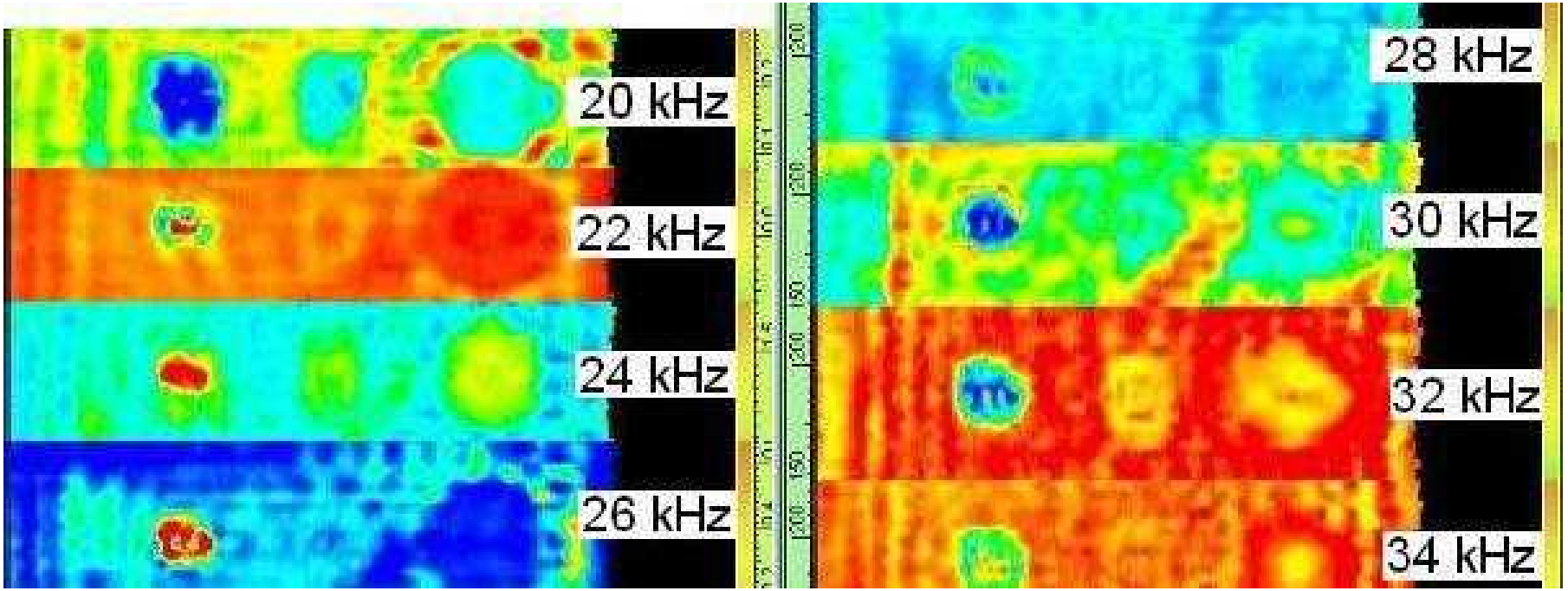


Disbond Delamination Potting

Disbond Delamination Potting

Observations

Variation of defect shape in function of frequency and position of the probe at frequency higher than 20 KHz

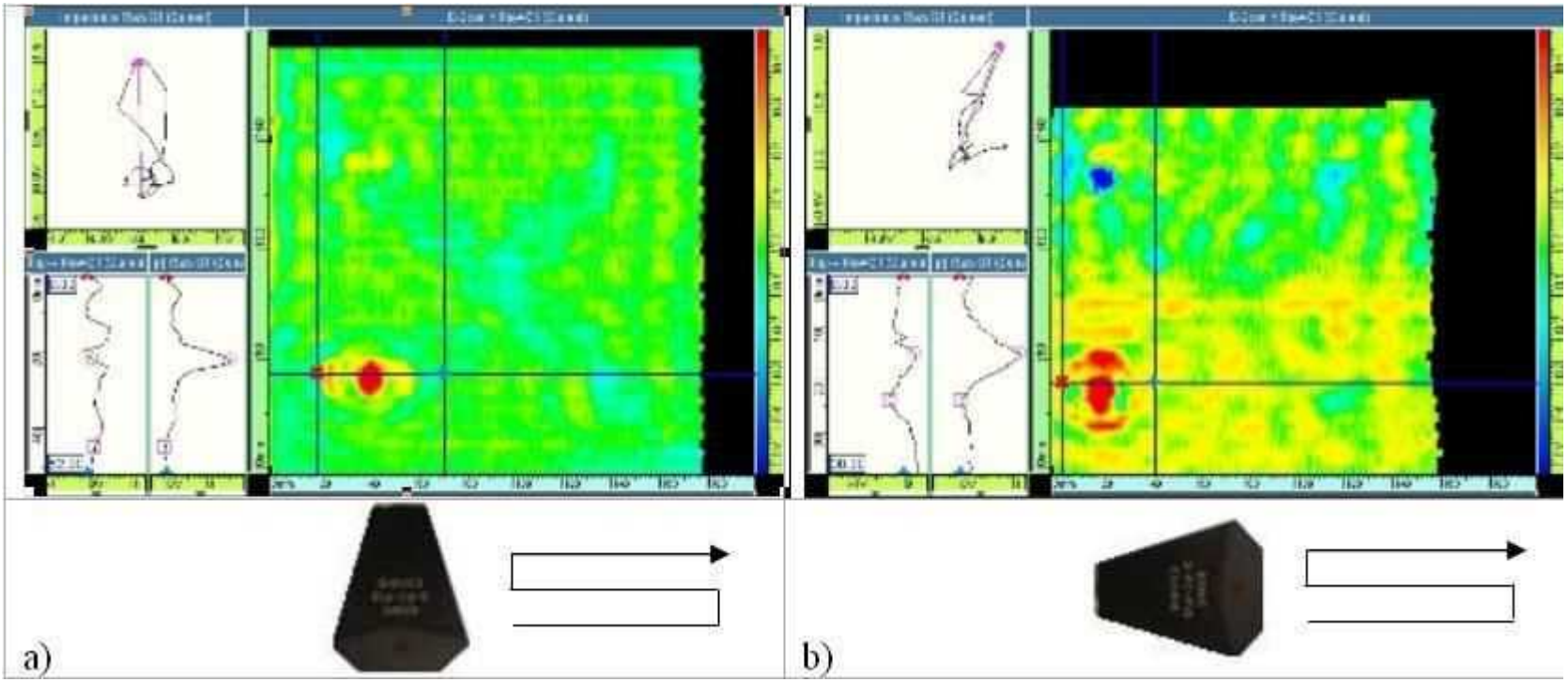


Disbond Delamination Potting

Disbond Delamination Potting

Observations

Variation of defect shape in function of frequency and position of the probe



Conclusions

The use of a single instrument offering multiple inspection methods allows inspection of a wide variety of composite materials and configurations.

The Pitch-catch, MIA, and Resonance methods, as discussed, each have particular advantages in terms of application solutions. These methods are defined in aircraft NDT manuals.

Portable Bond Tester C-scan imaging device can improve detectability, reliability C-scan imaging will be very helpful in damage assessment and repair requirements.