SAND2012-6727C

Assessment of Aerospace Components Using Resonant Inspection Techniques

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Outline

- Ultrasonic basics
- Resonant Inspection Theory
- Resonant Inspection Set-up and Application
- Resonant Capabilities and Limitations
- Conclusions

Ultrasonic Basics

To maximize sound energy level into a material, the air between the ultrasonic transducer and the test article must be removed. Couplant removes the air and transfers the sonic energy from the probe into the material under test. This presentation assess resonant inspection techniques to interrogate several aerospace materials and configurations.

- In immersion testing, the part and the transducer are placed in a tank filled with water. This arrangement allows better movement of the transducer while maintaining consistent coupling. Its disadvantage is that the part must sit in water for long periods of time.
- In contact testing, a couplant such as water, oil or a gel is applied between the transducer and the part. The sound entering the part is defined as the front surface. Thickness measurements can be obtained using time of flight measurements. The technique is manual and labor intensive. Signal interpretation is the key.

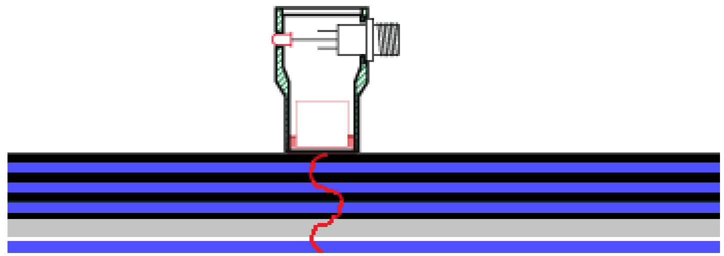
Ultrasonic Basics (continued)

A way to improve near surface resolution with a single element transducer is through the use of a delay line. Delay line transducers have a plastic piece that is placed in front of the transducer. This provides a time delay between the sound generation and reception of reflected energy. The plastic tip becomes the front surface of the composite. This plastic tip also encompasses the constructive/destructive sound fronts.

Resonant Inspection uses some of these basic facts to its advantage.

Resonance Inspection Basics

- Resonance inspection requires a highly resonant, narrowband transducer that can be excited at its natural resonance frequency. A tuned continuous standing wave is coupled into the material. Either couplant on the surface or water forced through a small tube near the probe tip is required.



- Resonant inspection can be used for several aerospace applications to compliment conventional ultrasonic inspection or used as stand-alone. The signal needs to be correlated to a part feature (honeycomb structure, composite thickness, defect, or reference standard). One technique is to place the probe in an area that is free from defects and establish the baseline signal. If this can not be accomplished then balancing the probe in air can be used as a starting point.
- The movement of the cursor tracks the changes in the signal amplitude (X) and phase (Y). Any changes in structural resonance is representative of thickness changes caused by the presence of disbonds, delaminations, or thinner composite sections. However, the **depth within the component can not be easily determined** without reference standards.

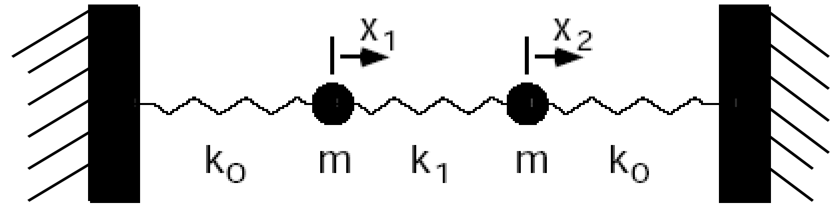
Resonance: A Page from History

- Oscillating harmonic motion has been studied for hundreds of years.
- Daniel Bernoulli and Leonard Euler studied oscillating systems from 1727 -1733.
- Bernoulli defined the single-degree-of-freedom using simple nodes. The frequencies of oscillation were determined (derived) for a simple system. Most of the work was to develop the understanding of harmonic vibrations with stringed musical instruments.
- Bernoulli continued to study oscillations from forced air into pipe organs. Although much of the groundwork for the theory of oscillations was done by Bernoulli, it was Joseph Lagrange who generalized oscillatory motion for a system of particles and degrees of freedom were defined.

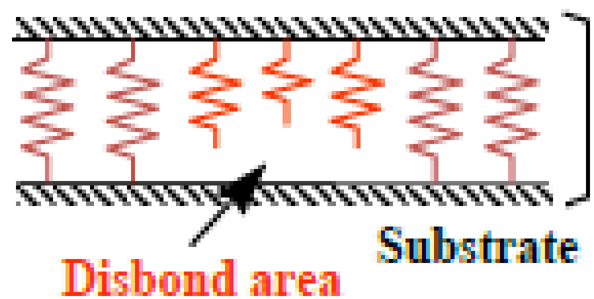
The Big Idea: Any motion which repeats itself after a certain interval of time is called vibration. Vibrations may be either free or forced. Any solid body is said to have free vibration if the periodic motion **CONTINUES after the** cause (input) is removed. However, if the vibratory motion persists because of the existence of the disturbing force (the probe) the it is called **FORCED** vibration. Any free vibration will eventually cease because of the loss of energy. We call this the damping factor. Natural frequencies are the key to resonant inspection.

Resonance (continued)

- A coupled harmonic oscillator will be used to explain the fundamental equations of motion. If motion is restricted to a line that connects m_1 and m_2. Then, x_1 and x_2 are the measured displacement values from the equilibrium position. This becomes a two degree of freedom system.



Masses are equal $m_1 = m_2 = m$
Both ends are fixed.
Original Spring stiffness k_0
Spring stiffness k_1 between masses



Resonance The Simple Case

Using Newton's second law ∑F = m**a;** the motion of the masses of the system are described by the equations below:

$$m\ddot{x}_1 + k_0 x_1 - k_1\left(x_2 - x_1\right) = 0$$

$$m\ddot{x}_2 + k_0 x_2 + k_1\left(x_2 - x_1\right) = 0$$

These differential equations are nontrivial due to the coupling displacement term $k_1(x_2-x_1)$. The resulting equations of motion reveal that there are two normal modes of motion of the mass, symmetric and anti-symmetric. All oscillations of the masses can be written as linear combinations of the two modes.

Free Vibration with Damping

$$m\ddot{x} + c\dot{x} + kx = \{F(t)\} = F_0 \cos \Omega t$$

Let F {t} be zero. Then if we divide each term by the mass m and substitute λ for x. The equation becomes:

$$\lambda^2 + \frac{c}{m}\lambda + \frac{k}{m} = 0$$

If we solve the above equation with known boundary conditions additional relationships can be found. In this case the structural configuration is a beam.

$$w_n = \sqrt{k/m} = 2\pi f_n = \sqrt{3EIg / wl^3}$$

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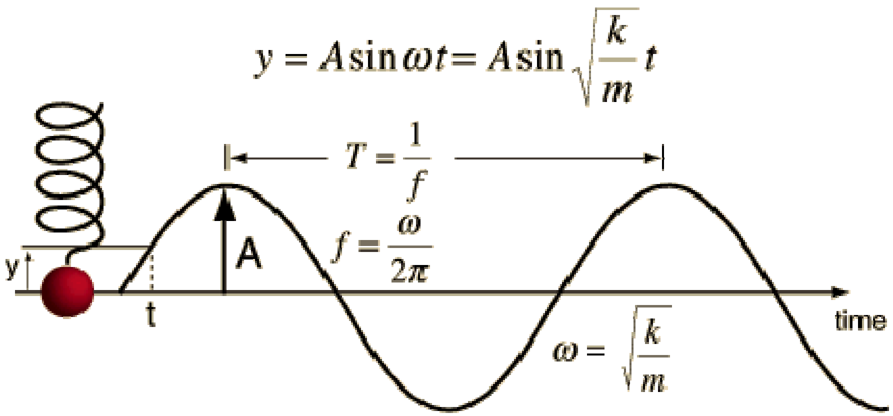
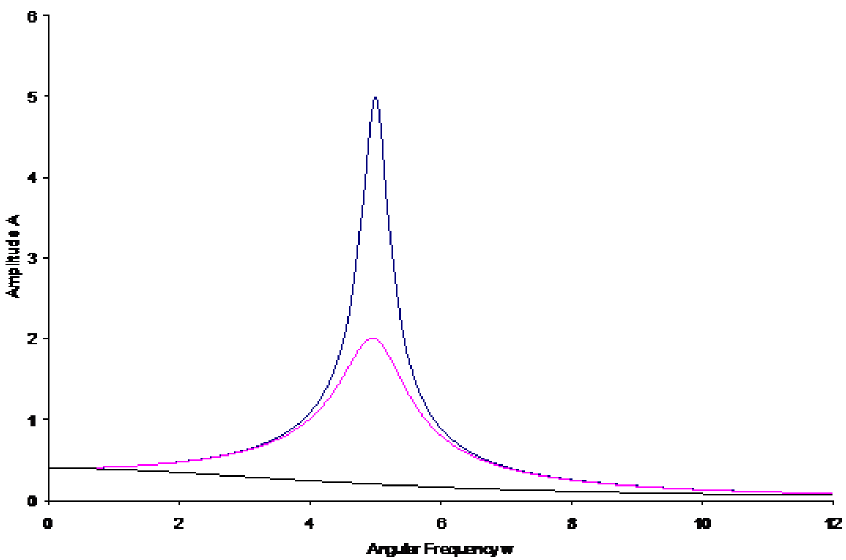
Simple Harmonic Motion



The inspector gets to pick:

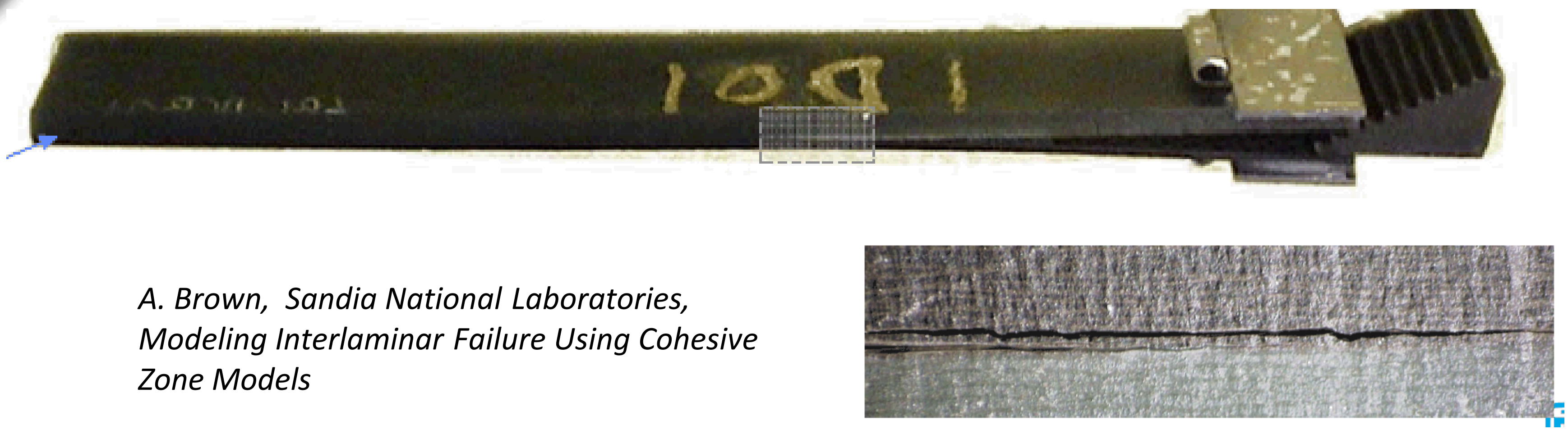
- the probe
- the frequency
- inspection system



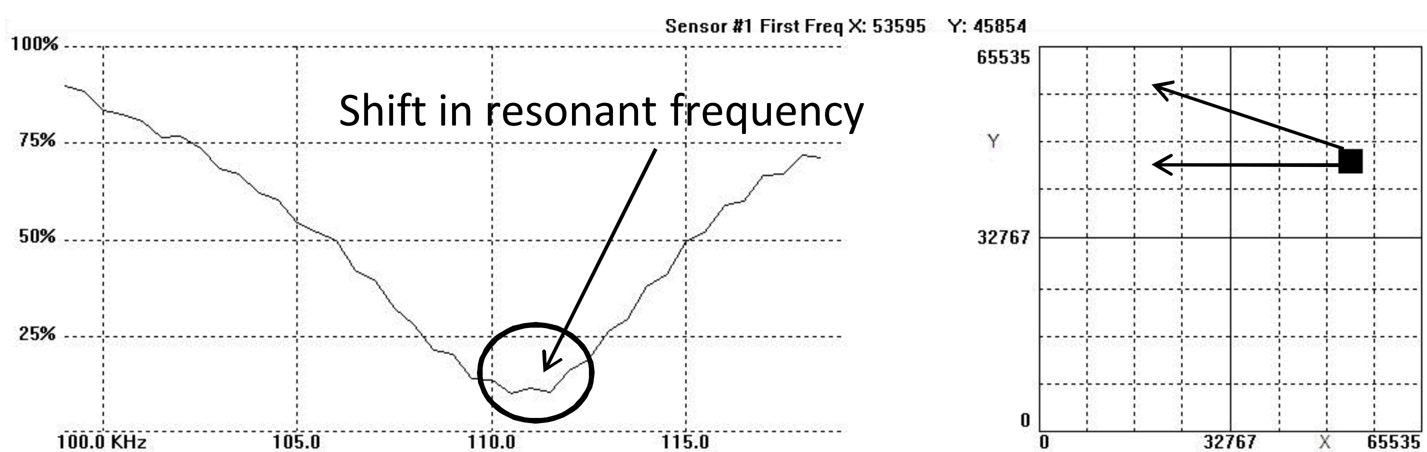
The occurrence of a maximum amplitude (oscillation) is referred to as "resonance". If damping is sufficiently strong (increased mass) then natural resonance does not occur easily. Note: Resonant frequency must be a real number and cannot take on a complex form.

Source: http://hyperphysics.phy-astr.gsu.edu/hbase/shm2.html#c2

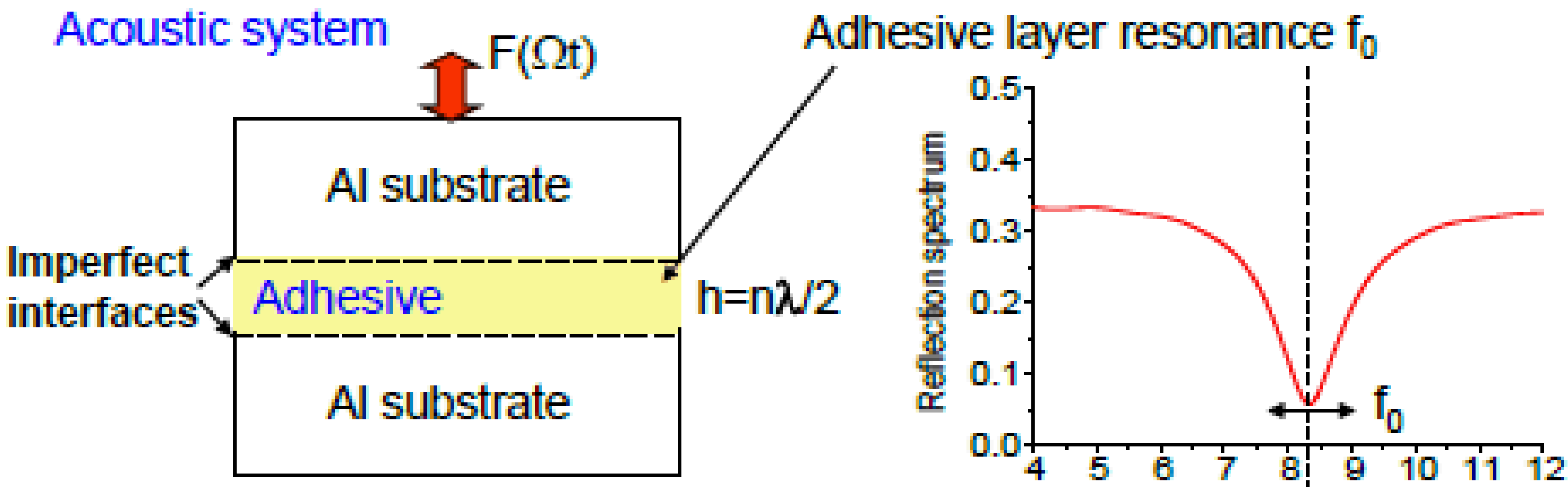
Resonant Inspection to Aid Modeling



A. Brown, Sandia National Laboratories, Modeling Interlaminar Failure Using Cohesive Zone Models



Resonant Inspection to Detect Disbonds



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Monitored amplitude shifts as the adhesive fabrication was changed.

Rule of thumb: thickness of part divided by the material velocity give you an Idea of the frequency response.

MAUS Inspection Experiments

MAUS = Mobile Automated Scanner

Thick solid laminate with holes drilled at various depths and diameters

Thin 6 ply solid laminate with foreign objects placed in the fiber weave during manufacturing.

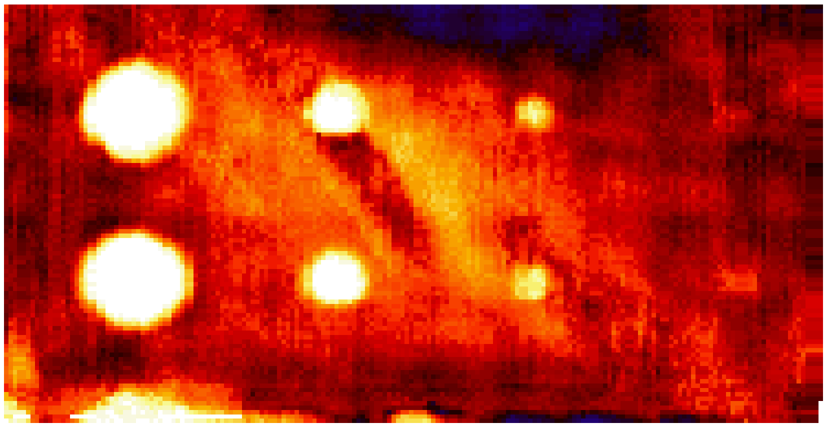
Honeycomb core bonded onto between two thin sheets of 2024 T6 aluminum.

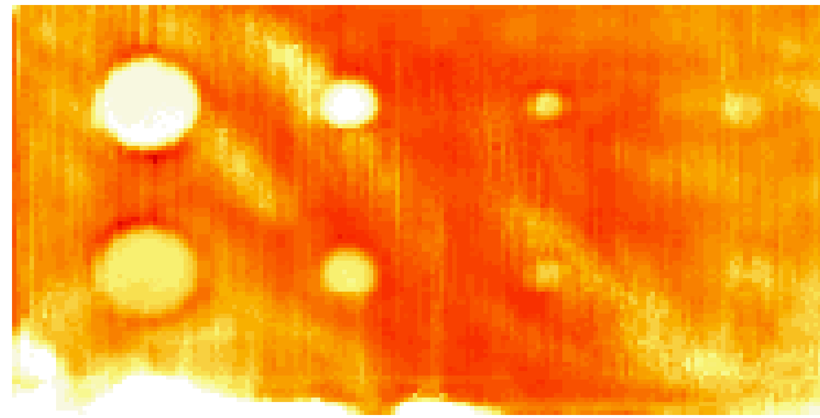
Thick weaves with several layers of substructure.

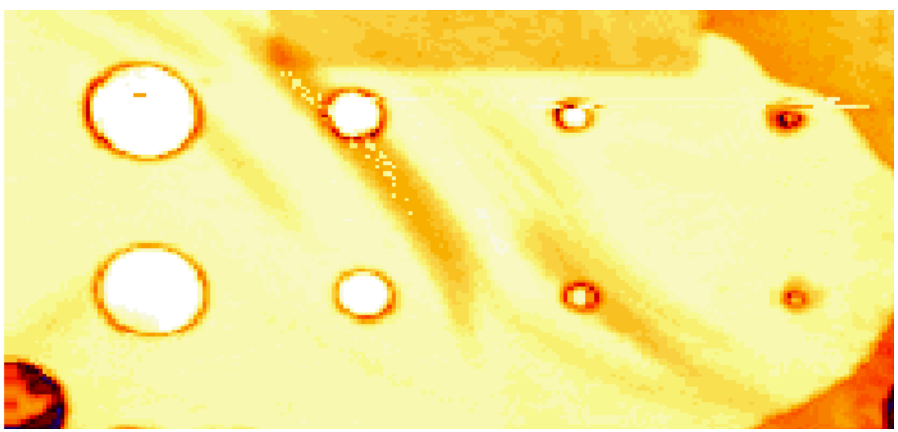
Thick Composite Structures

Signal amplitude (X)

Phase angle (Y)

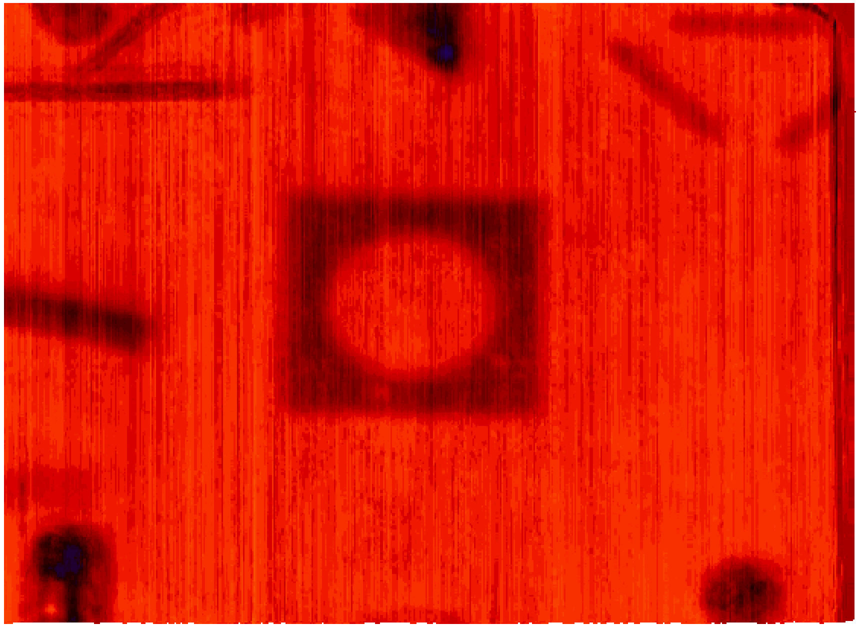




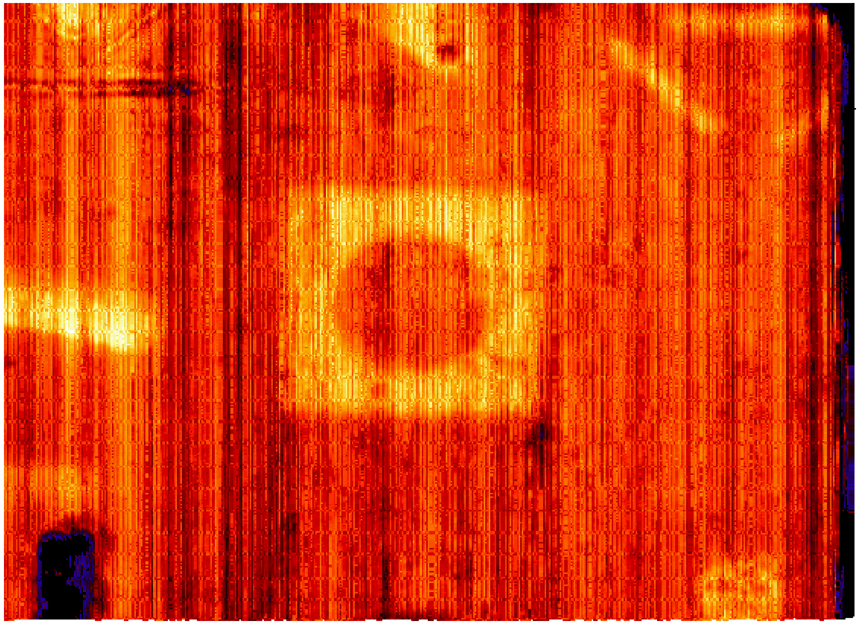


Contact ultrasonic Inspection (10 Mhz)

Object Detection Within Composites



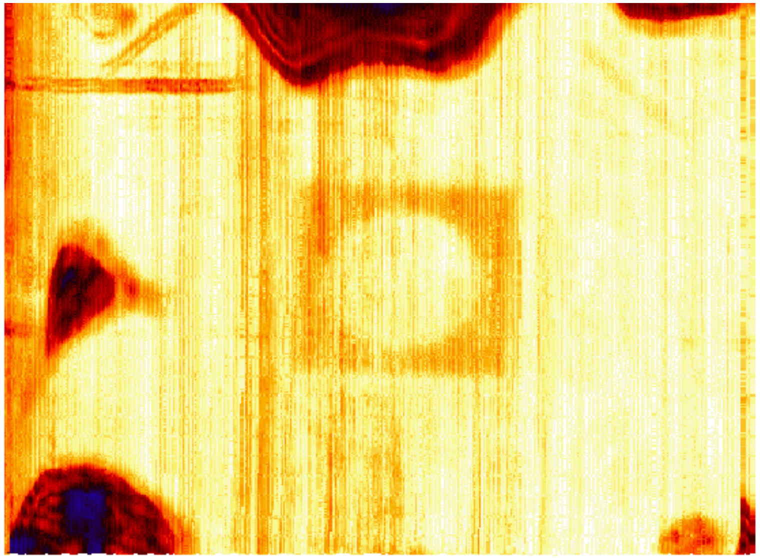
Signal amplitude (X)



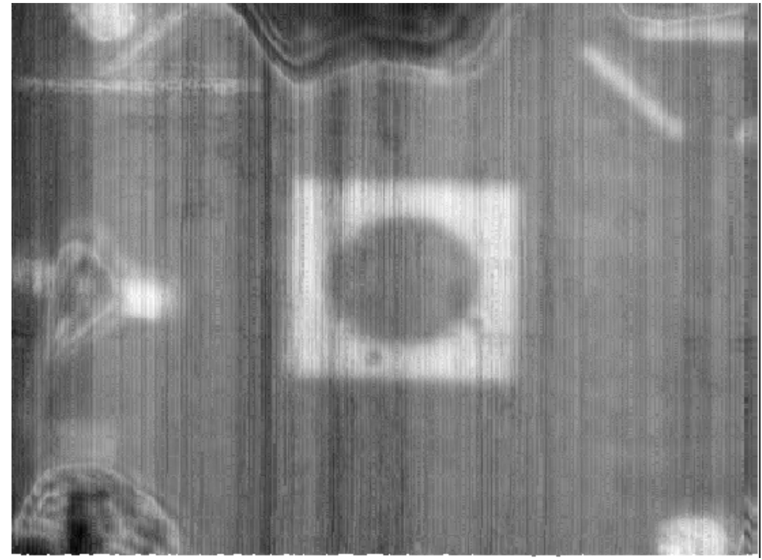
Phase angle (Y)

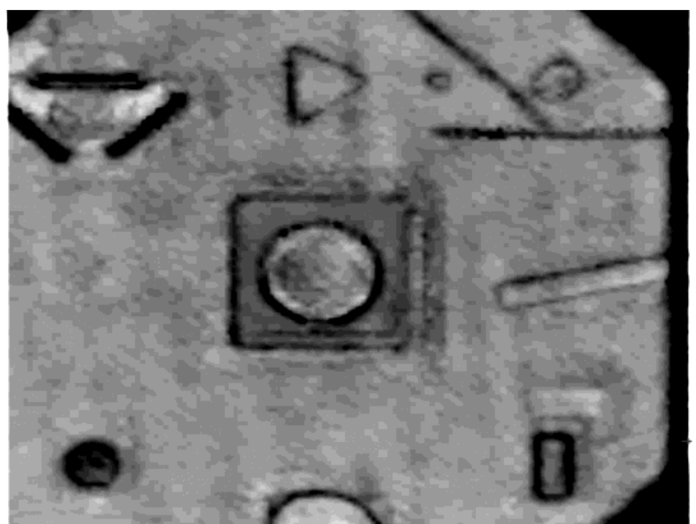
Contrast and Color Adjustments

Signal amplitude (X)



Phase angle (Y)





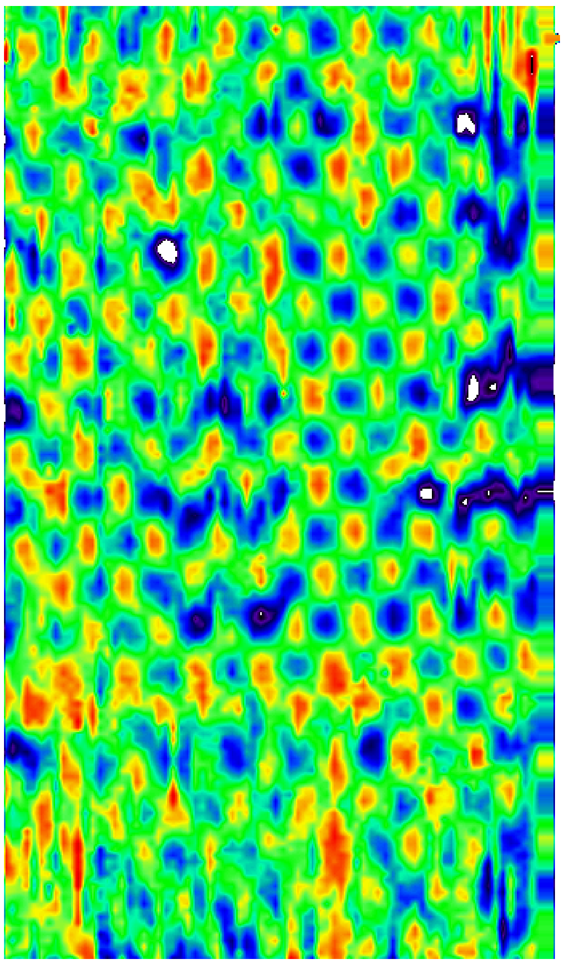
Contact ultrasonic Inspection (10 Mhz) amplitude gate.

Ultrasonic Thickness Resonant Correlation

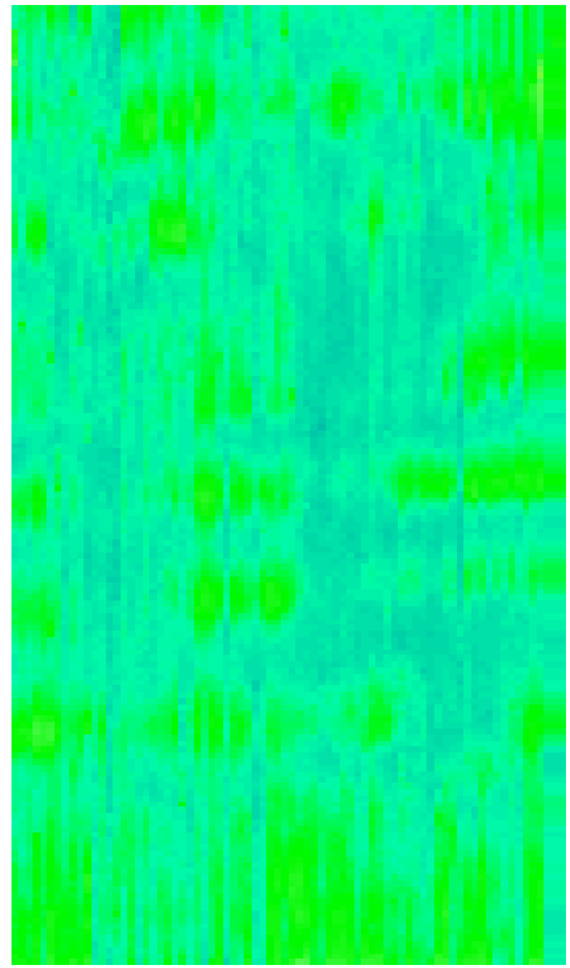
Contact ultrasonic Inspection (10 Mhz) with depth gate.

Aluminum/Honeycomb Structure

Frequency selected ~ 109 KHz



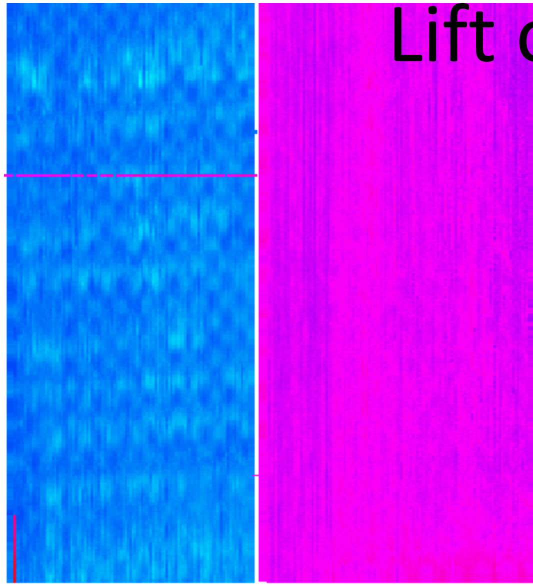
Signal amplitude (X)



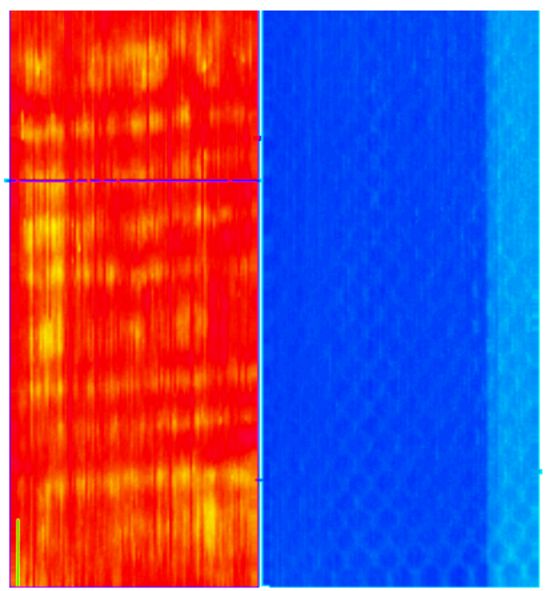
Phase angle (Y)

Aluminum/Honeycomb Structure

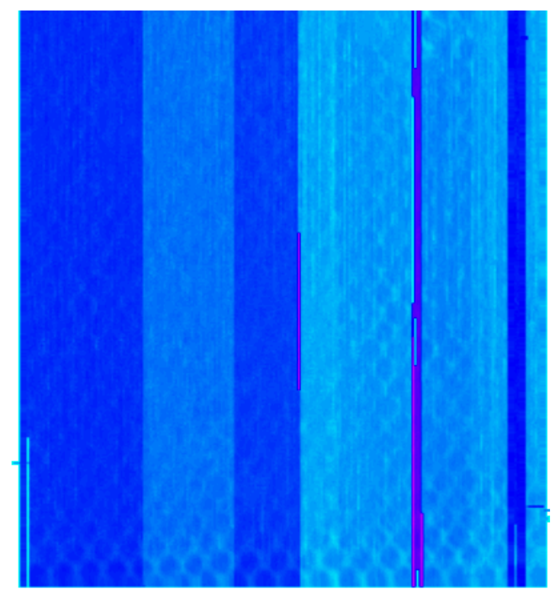
Lift off adjustment



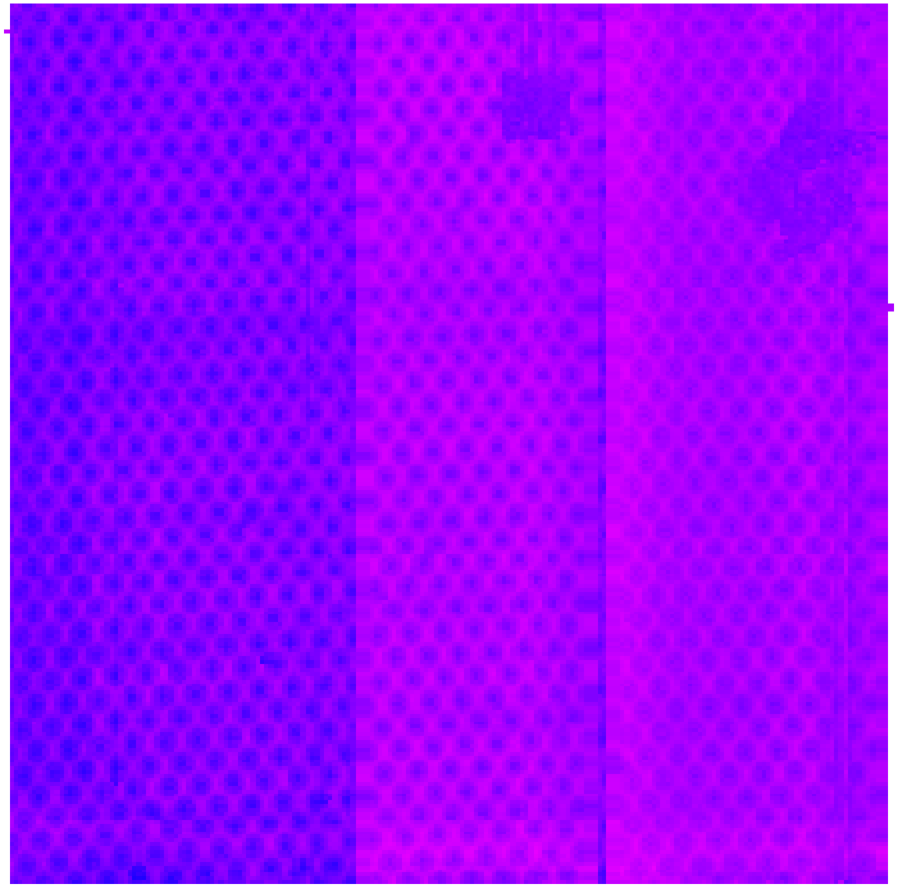
Signal Amplitude (X)



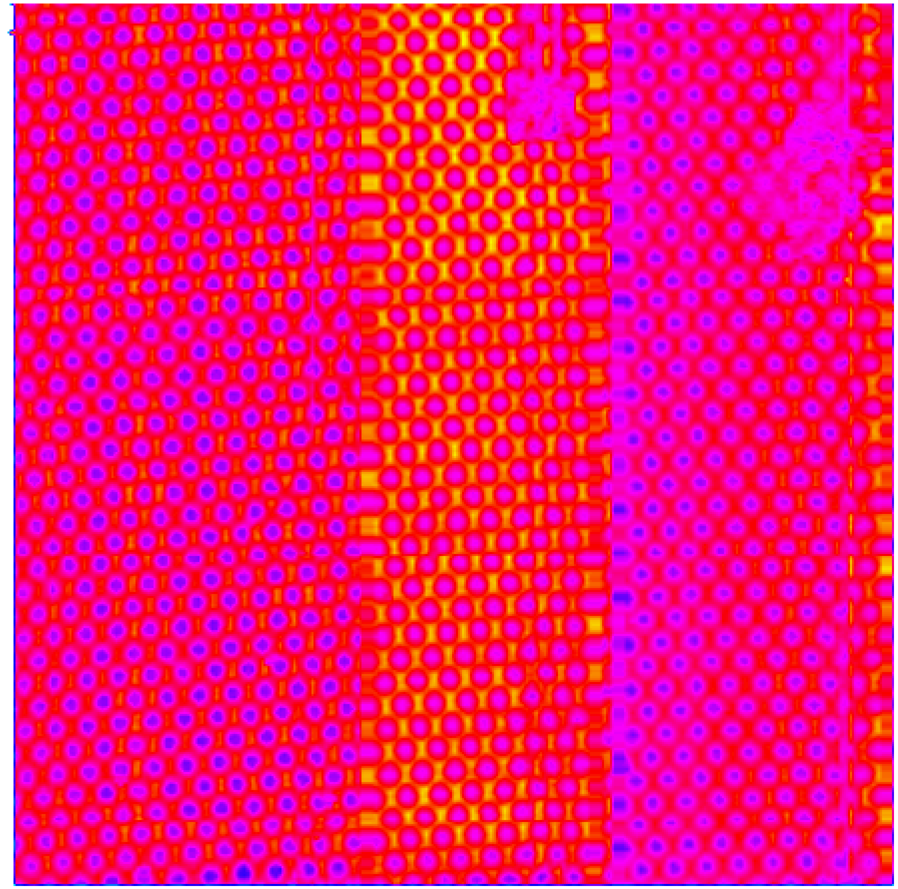
Phase angle (Y)



Comparison of Resonant and Mechanical Impedance Analysis



Signal amplitude (X)

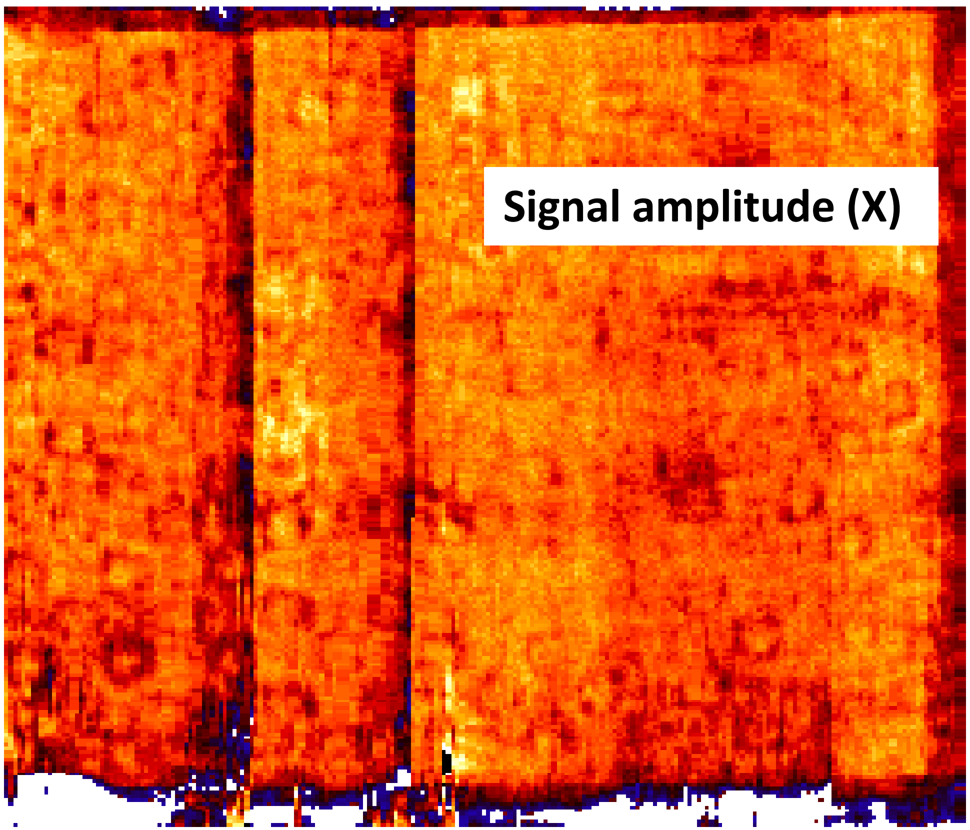


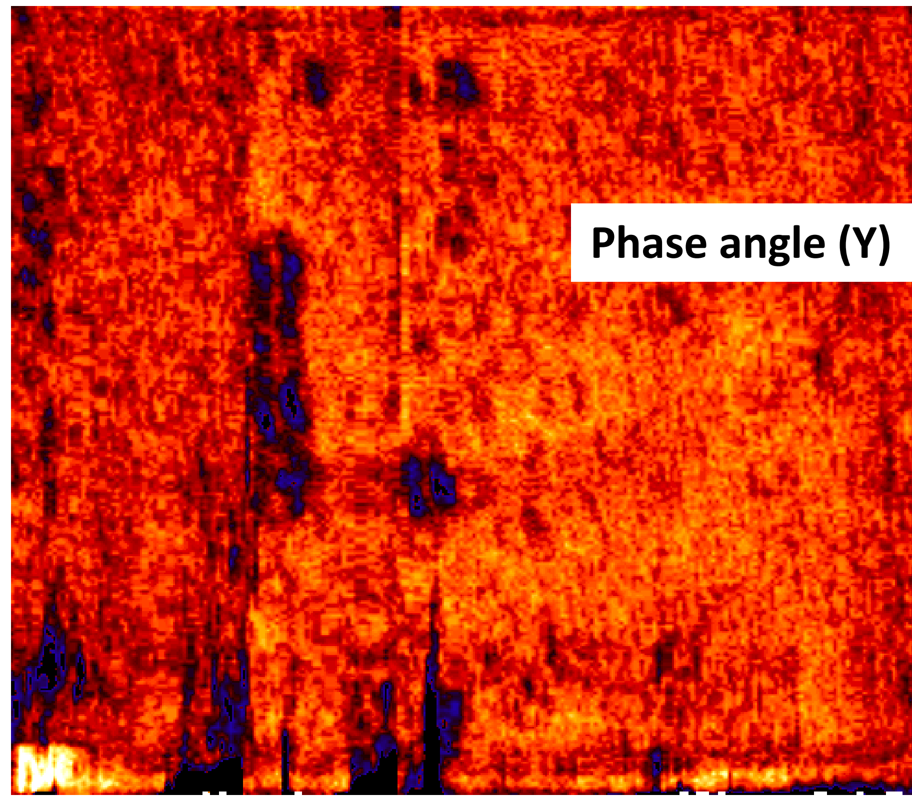
Signal amplitude (X)

Technique Development

Scanning a section of the part, changing settings and then rescanning will shorten technique development times.

Caution: TAKE GOOD NOTES





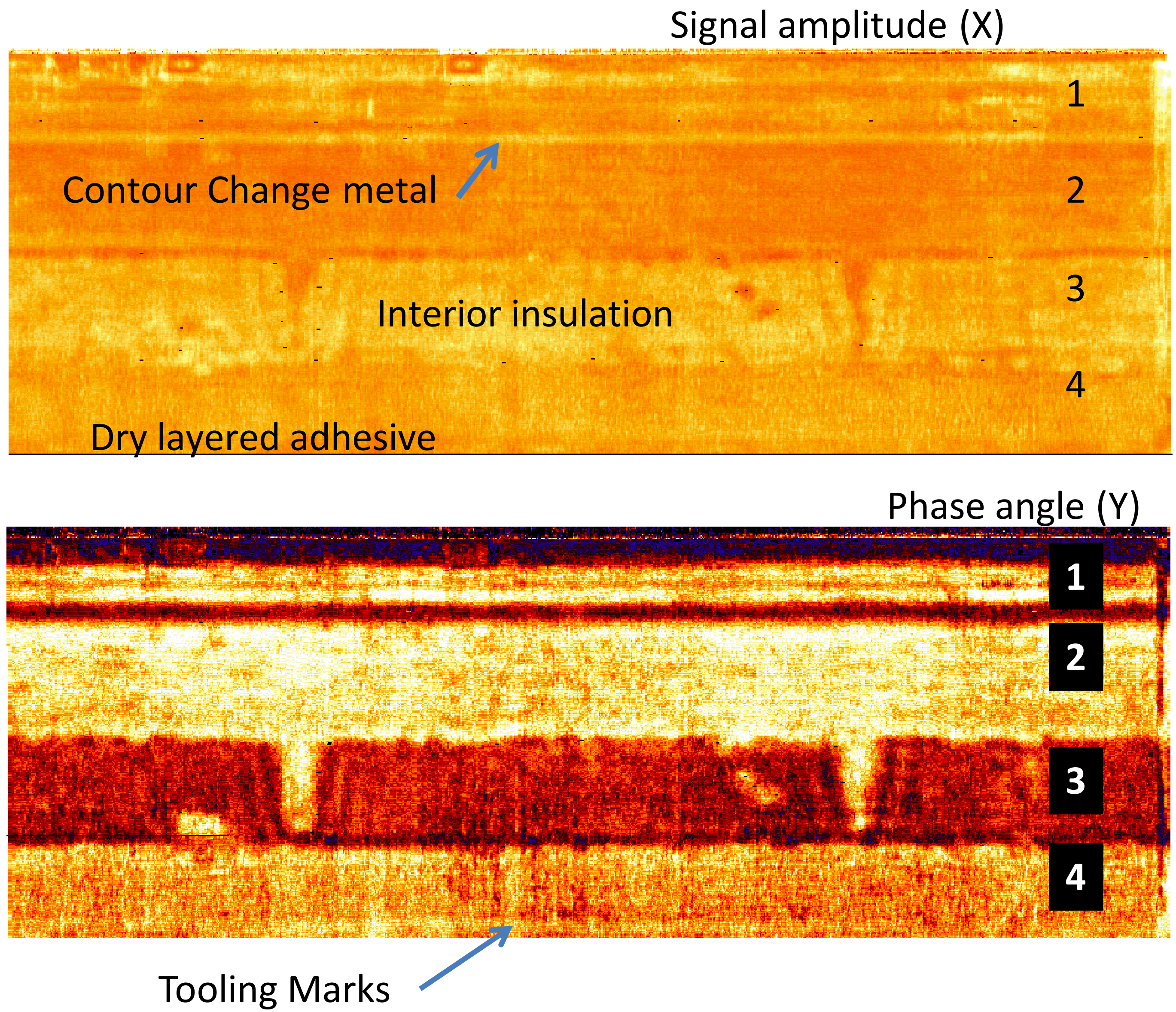
Resonant Inspection

Resonant inspection was performed on a aerospace structure using the MAUS automated scanner system. The probe was placed on an area that was free from defects. The movement of the cursor tracked the changes in the signal amplitude (X) and phase angle (Y). The resonant probe scanned a section while the scanner indexed around the part. The component was interrogated for subsurface defects. This technique was able to transmit energy through the entire thickness of the part.

Resonant Inspection Results

The frequency selected was able to transmit energy through the entire structure (composite, bondline, aircraft aluminum and substructure)

Four distinct bands were detected. The inside was visually inspected and contained several structures that changed the resonant response. The bands are: aluminum, insulation, dry thick adhesive caused from dry layered adhesive removal.



Conclusions

- The pulse echo ultrasonic technique gives the highest resolution to detect and characterize a homogeneous material.
- Resonant inspection allows direct correlation to a part's mechanical response.
- The MAUS system is easy to transport and can be placed almost anywhere to allow for rapid in process feedback.