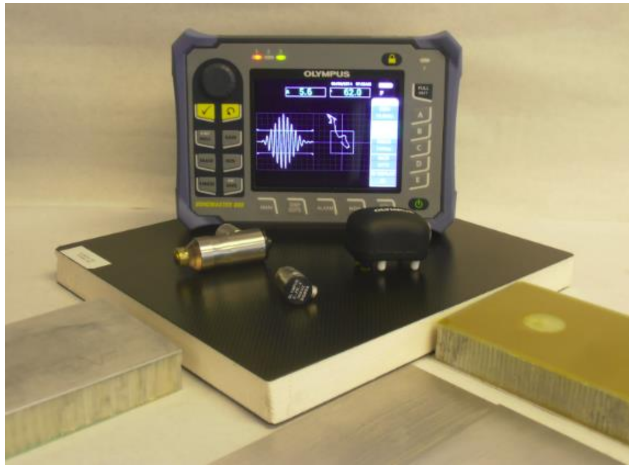
JAMES BITTNER | SEPTEMBER 16–19, 2024 | AIRLINES FOR AMERICA (A4A) NONDESTRUCTIVE TESTING (NDT) FORUM, NASHVILLE, TN

Resonance Bond Testing

Resonance Testing—An In-Depth Look at This Technology

Bond Testing Technology

- Resonance bond testing technology has been around for more than 40 years as a nondestructive testing technology that is used to detect defects in composite and bonded structures.

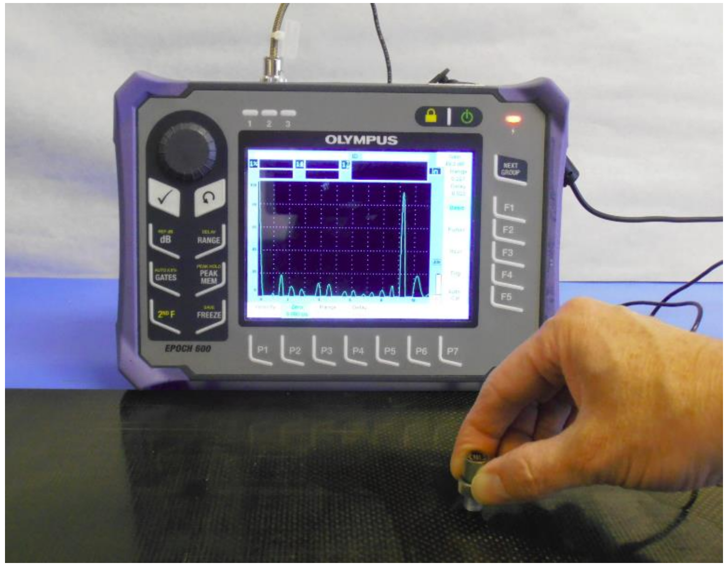


- Even though this technology has been around for many years, resonance testing remains one of the most misunderstood NDT methods.

Resonance Testing Method

- There are distinct differences when comparing resonance testing with ultrasonic inspection. With ultrasonic testing, the transducer is coupled to the test material, and then echoes are detected to determine if flaws are present or there are changes in the material thickness. This method relies on sound path propagation and time of flight.
- Resonance bond testing does not operate on the principle of sound propagation velocity or reflected sound. The resonance only changes in the phase and amplitude of the propagating or the standing wave measured within the probe.

Ultrasonic testing (EPOCH™ series flaw detector)



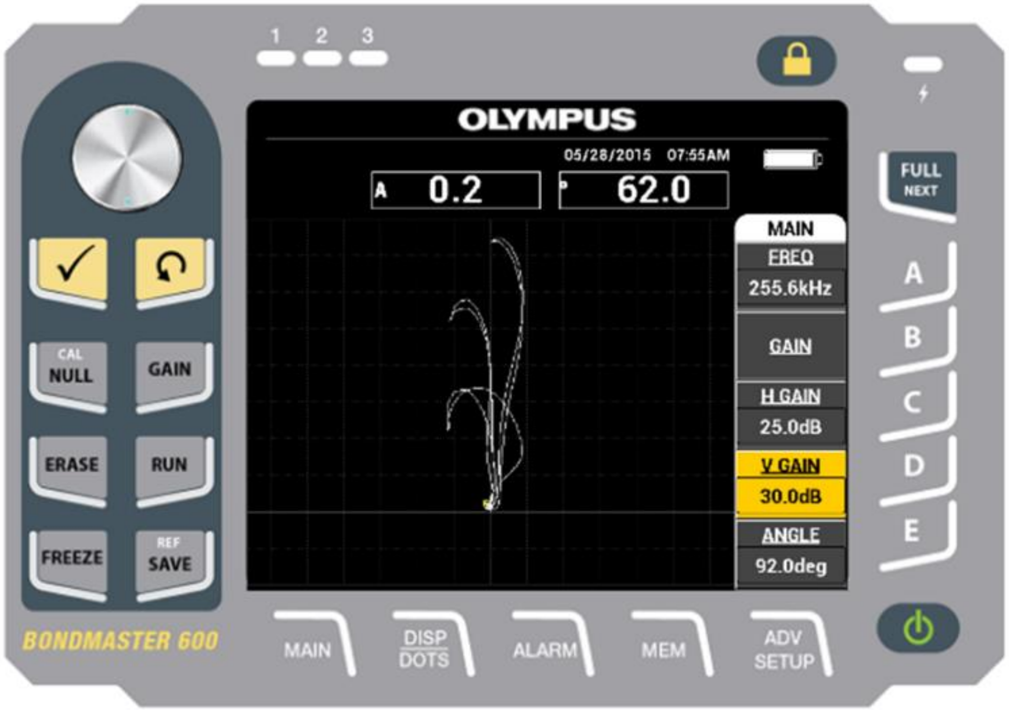
Bond testing (BondMaster™ 600 flaw detector)

Resonance Testing Method

- The test is based on the change in the impedance of the resonant Q while the probe is acoustically coupled to the test material.

- The measured impedance within the probe is affected by the acoustic impedances of the test material. If there is a thickness change or delamination within the test material, there will be a change in the standing wave within the probe.

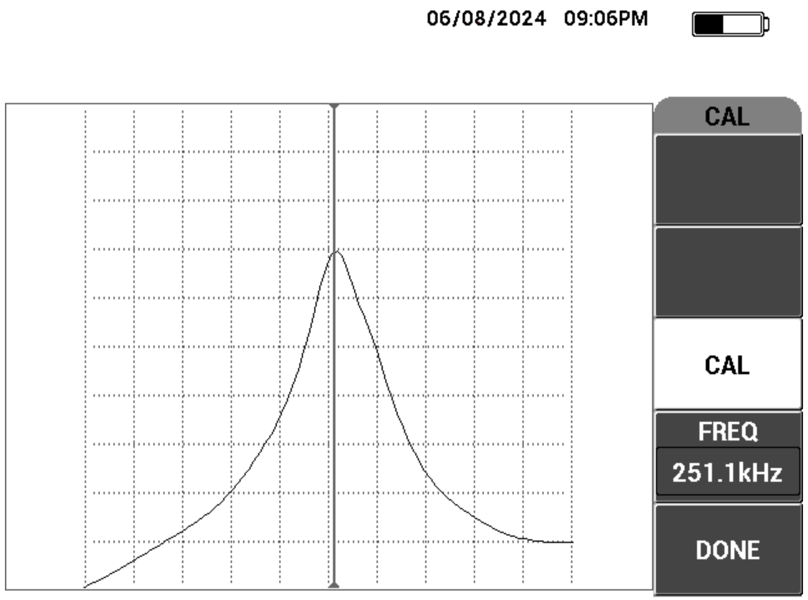
- Similar to eddy current, bond testing is a comparative inspection technique that requires accurate reference standards for signal setup, calibration, and analysis.



Resonance Testing Method

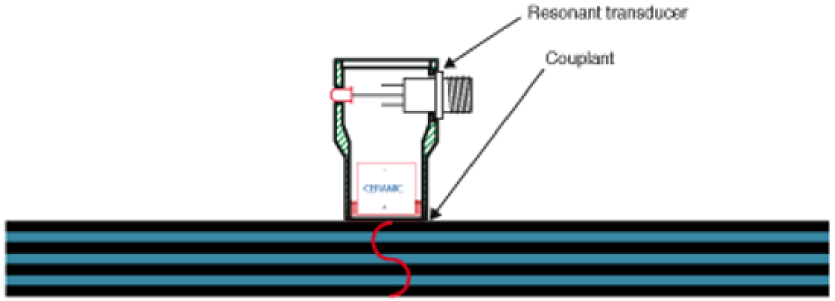
- Resonance testing uses special narrow-bandwidth "sonic" contact resonance probes.
- The probe automatically selects the resonance frequency, and the instrument balances the probe in air by sweeping over the frequency range and locating the phase null.
- The sonic probe is driven at its resonance frequency and coupled to the test part using a low-viscosity couplant.

The probe's standing wave

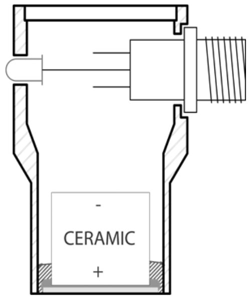


Resonance Testing Method

- Resonance bond testing measures variations in the probe's resonant frequency. We are measuring the electrical impedance changes in the resonance probe. The mechanical impedance of the test material is affecting the electrical impedance of the probe.



- Resonance probes are essentially undamped piezoceramic sonic probes.
- These probes are undamped to maximize the probe's resonance frequency.



Cross-sectional view

Resonance Testing Method

Resonance probes:

- Operate in the kilohertz (kHz) frequency range.
- Depending on the manufacturer, the frequency range for resonance probes can be from 25 kHz to 500 kHz.
- Frequency range for the probes offered by Evident: 35 kHz to 330 kHz.
- Like ultrasonic testing, probe selection is based on the material thickness:
  - The thicker the test material, the lower the frequency.
  - The thinner the test material, the higher the frequency.

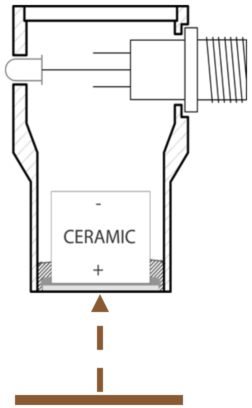
- S-PR-1 35 kHz (±5 kHz) in a 15.9 mm (0.625 in.) diameter case.
- S-PR-2 65 kHz (±10 kHz) in a 15.9 mm (0.625 in.) diameter case.
- S-PR-3 110 kHz (±10 kHz) in a 15.9 mm (0.625 in.) diameter case.
- S-PR-4 165 kHz (±10 kHz) in a 12.7 mm (0.500 in.) diameter case.
- S-PR-5 250 kHz (±10 kHz) in a 9.5 mm (0.375 in.) diameter case.
- S-PR-6 330 kHz (±10 kHz) in a 9.5 mm (0.375 in.) diameter case.

Resonance Testing Method

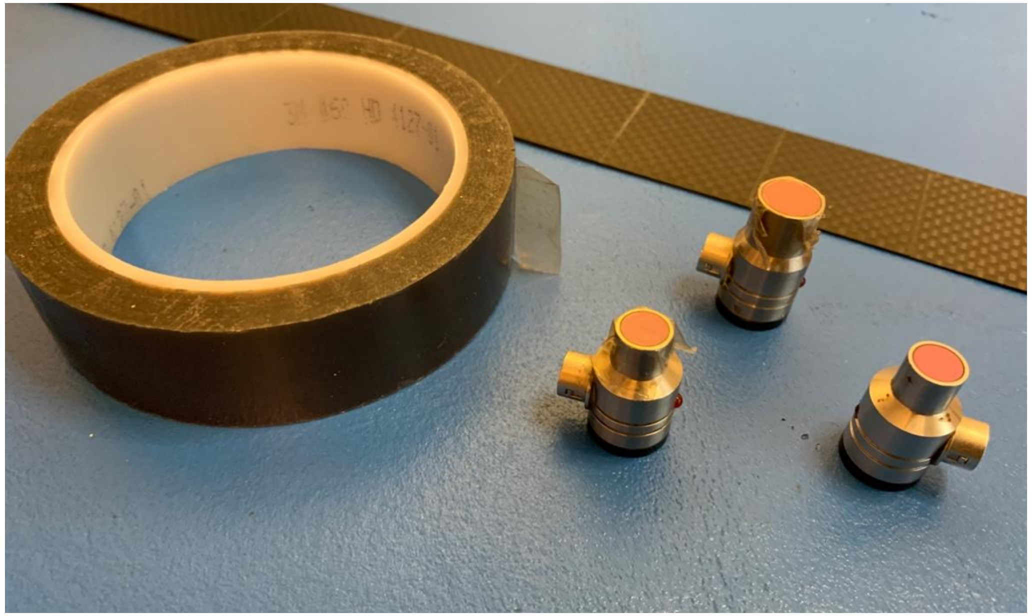
Wear face of resonance probes:

- Resonance probes should always have Teflon tape on the face of the probe to act as a wear face.

- The tape acts as a wear face and protects the element from wear and damage.



Teflon tape



Resonance Testing Method

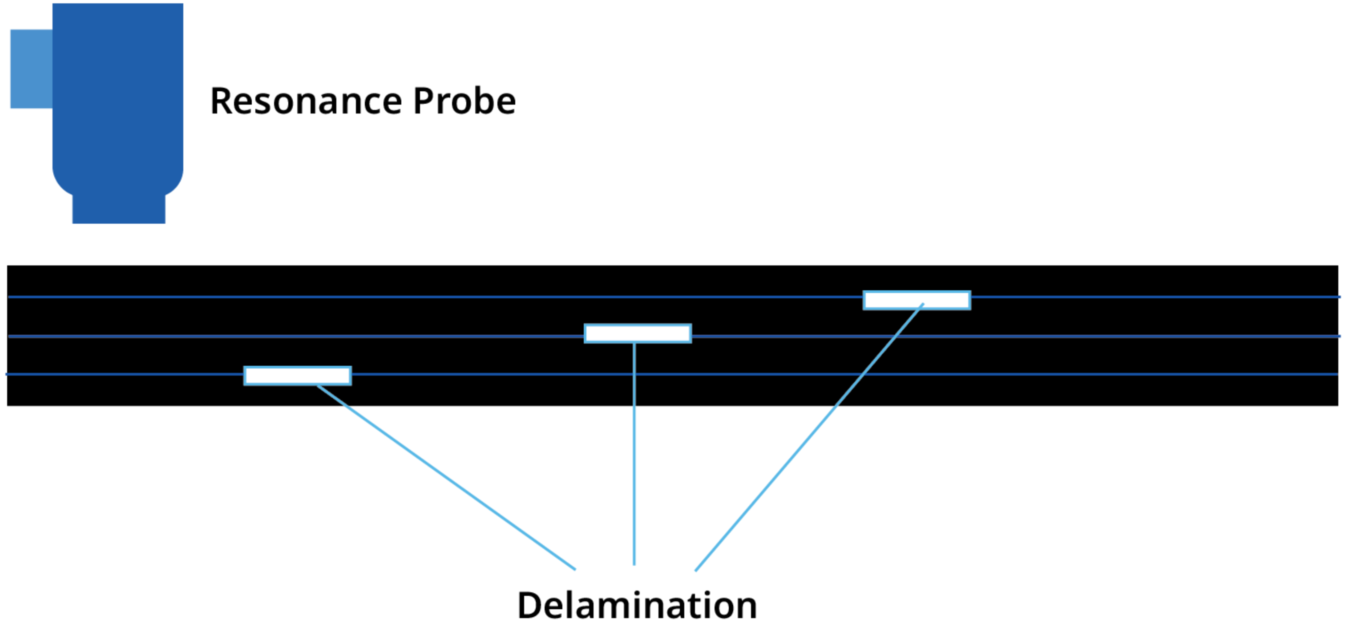
Couplant of resonance probes:

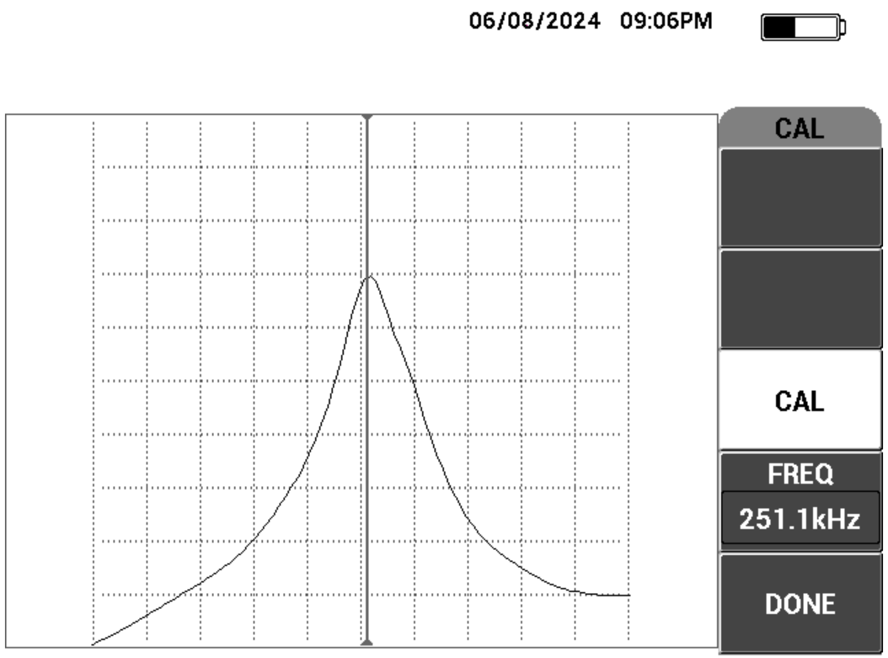
- As referenced earlier, resonance testing uses a low-viscosity couplant.
- The alternative couple debate: can water be used in place of resonance low-viscosity couplant?
- Yes, it greatly depends on the surface condition of the test material.

- Is the working surface smooth and glossy?
- Is the working surface rough and matted?
- Critical factor is the surface tension of the working surface.
- Experiment by mixing ultrasonic gel with water.

Resonance Testing Method

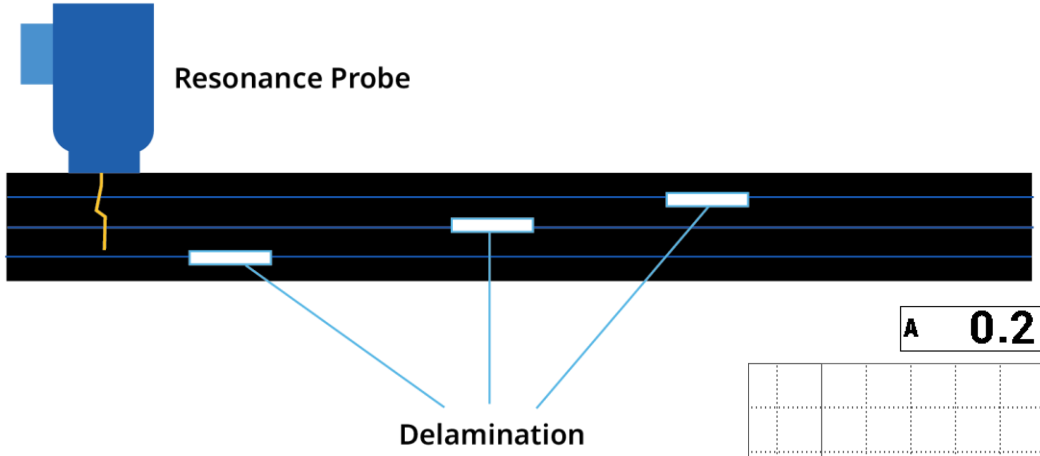
- Using the BondMaster 600 calibration menu, we can see the changes to the probe’s resonance frequency. The frequency change is due to the influence of the test sample's acoustic impedances of the material used to build the test sample.
- The test material is a carbon fiber reinforced polymer (CFRP) composite solid laminate with three simulated engineered delaminations at varying depths.
- We are looking at the probe’s resonance-swept frequency while the probe is in the air: “the standing wave.”

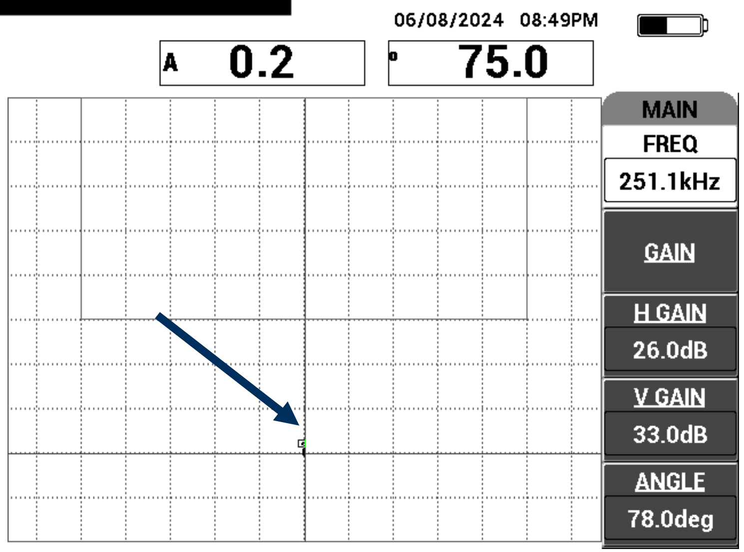


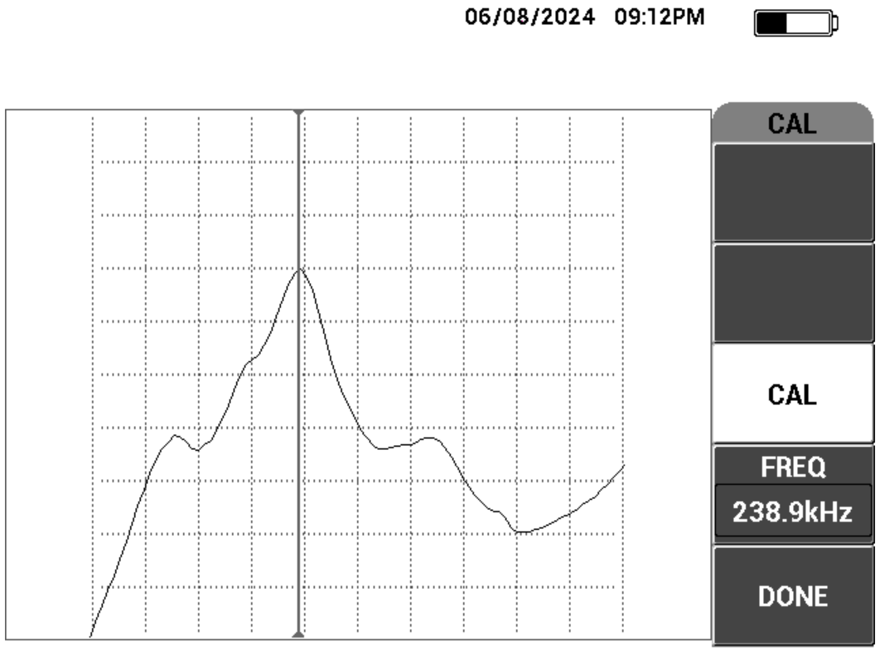


Resonance Testing Method

- Resonance probe is null/balanced on the test sample. The signal on the left is the X/Y impedance plane, and the signal on the right is the swept signal.
- CFRP test sample has influenced the probe's operating frequency from 251.1 kHz to 238.9 kHz on the good condition of the test sample.

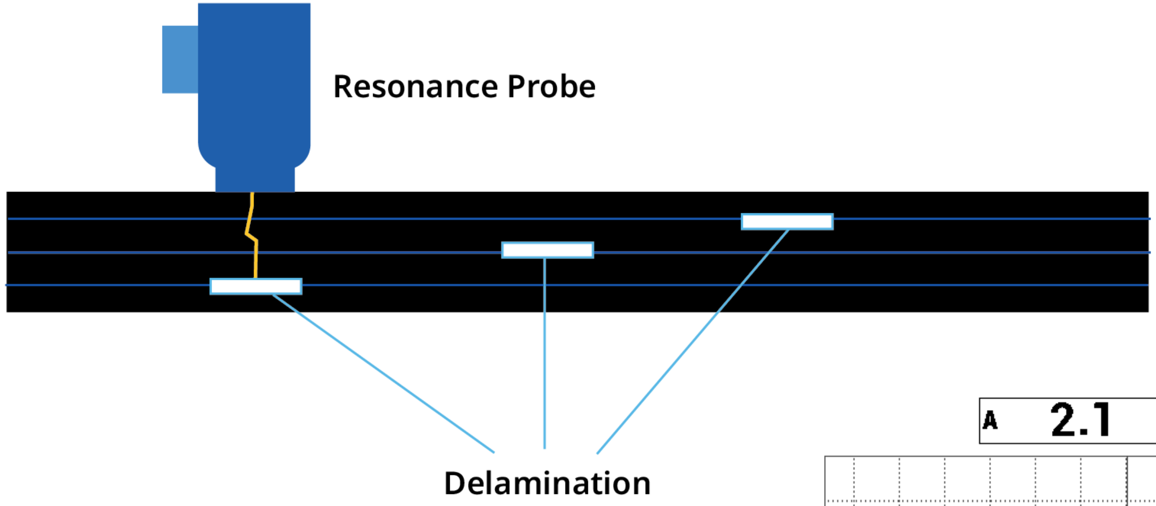


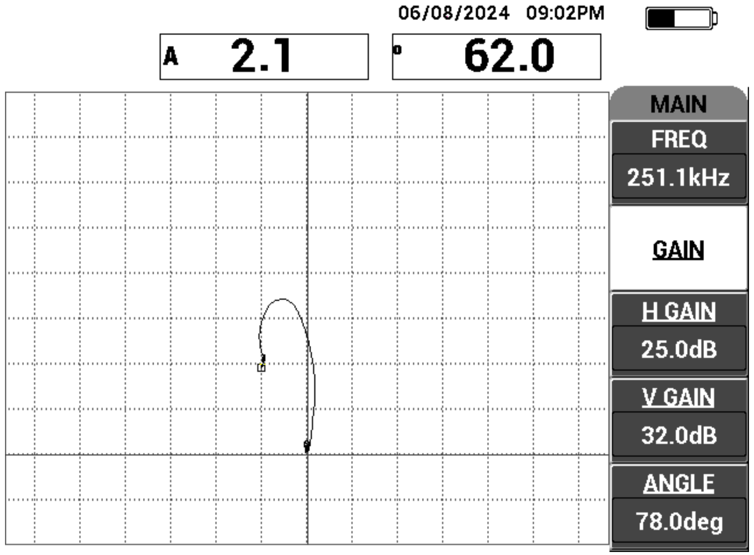


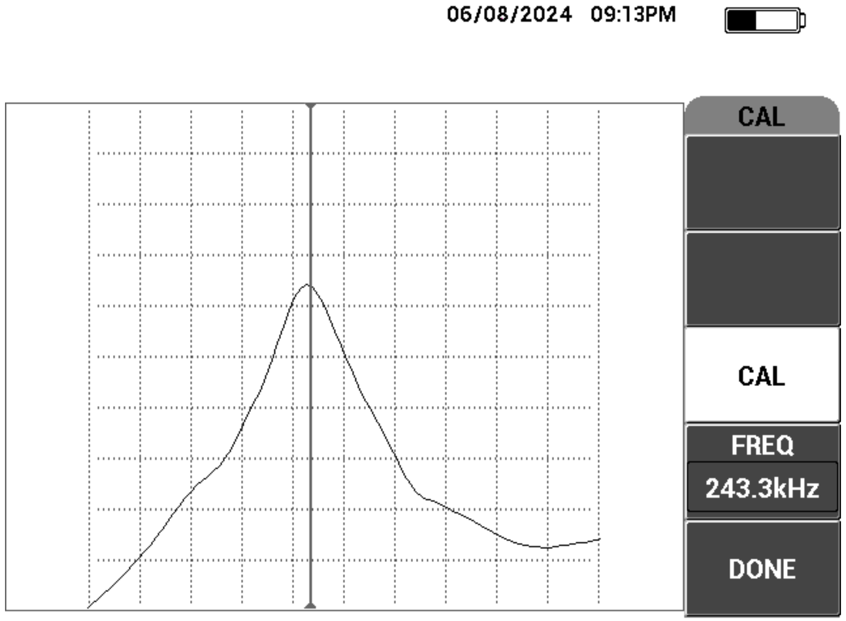


Resonance Testing Method

- First engineered delamination in the test sample. The probe's operating frequency is now 243.3 kHz.

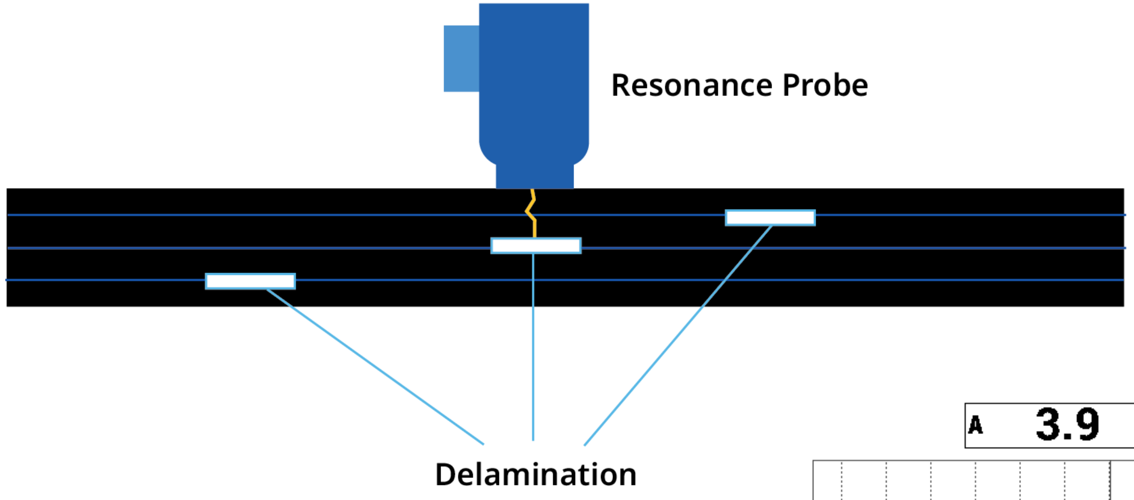


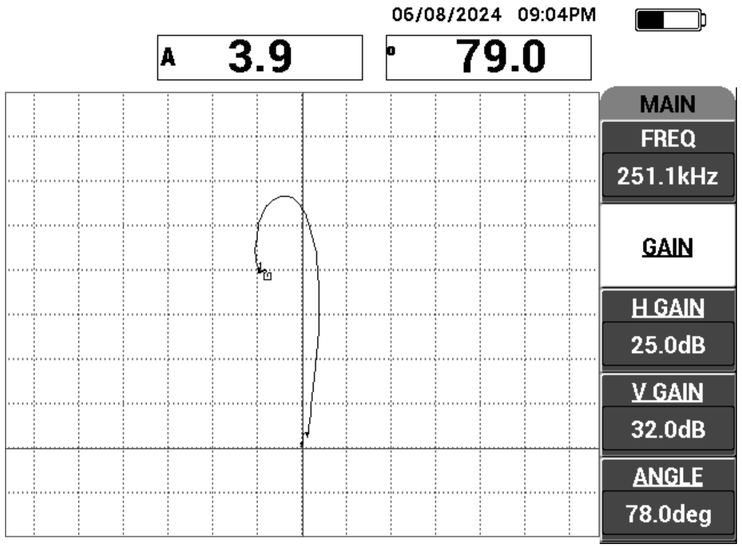


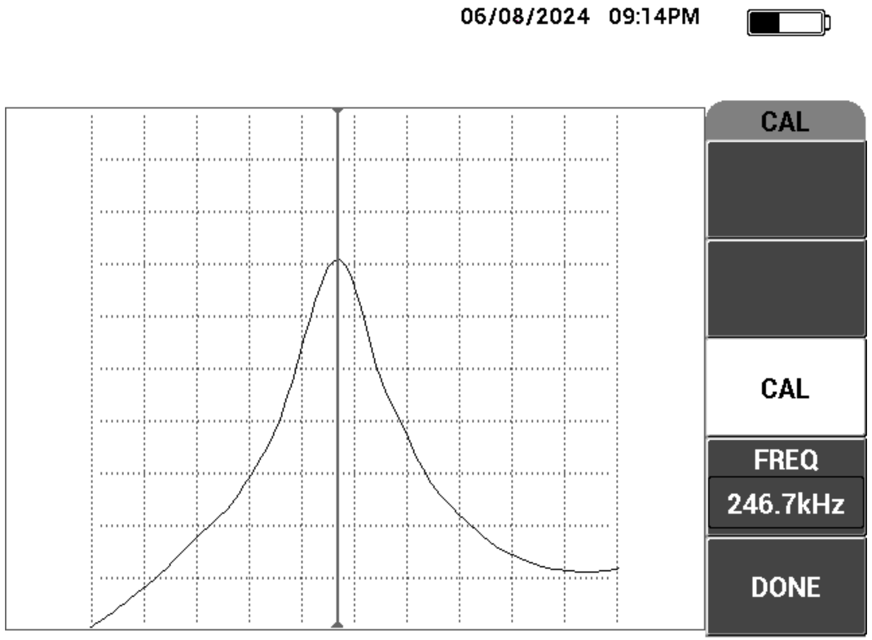


Resonance Testing Method

- Second engineered delamination in the test sample. The probe's operating frequency is now 246.7 kHz.

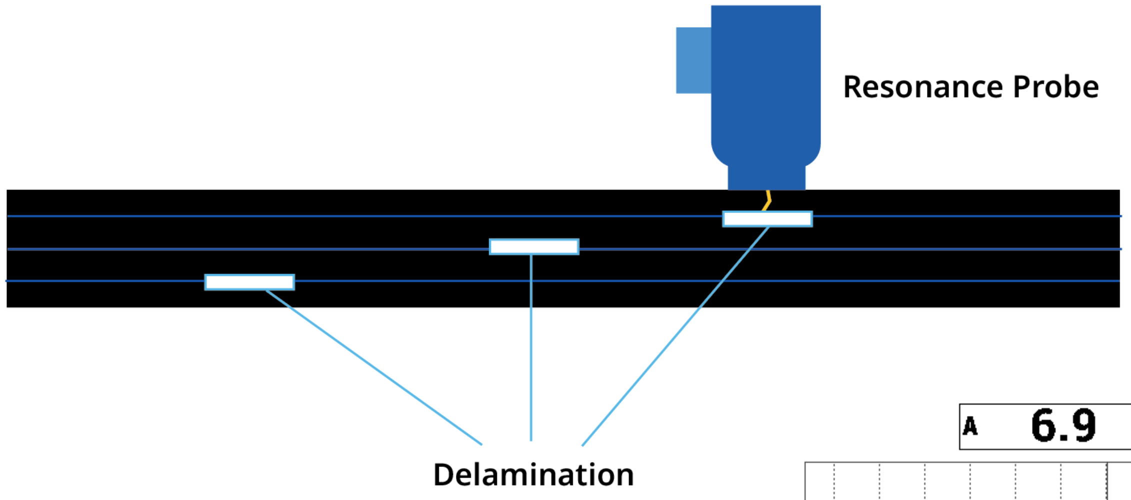


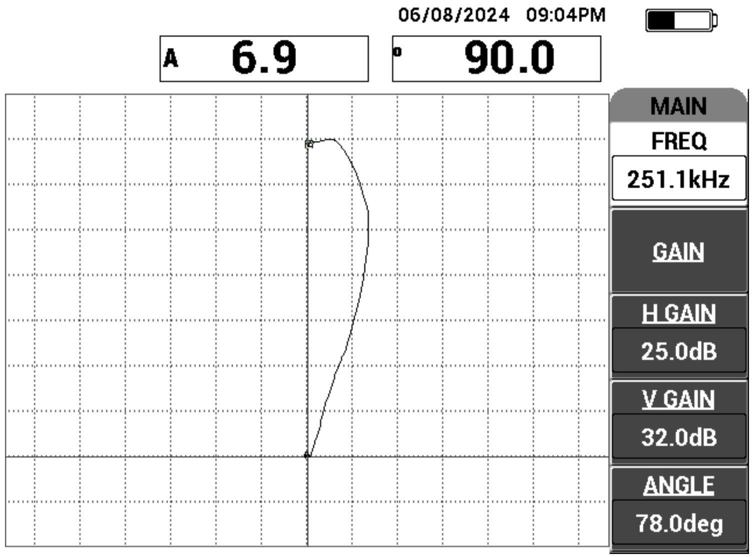


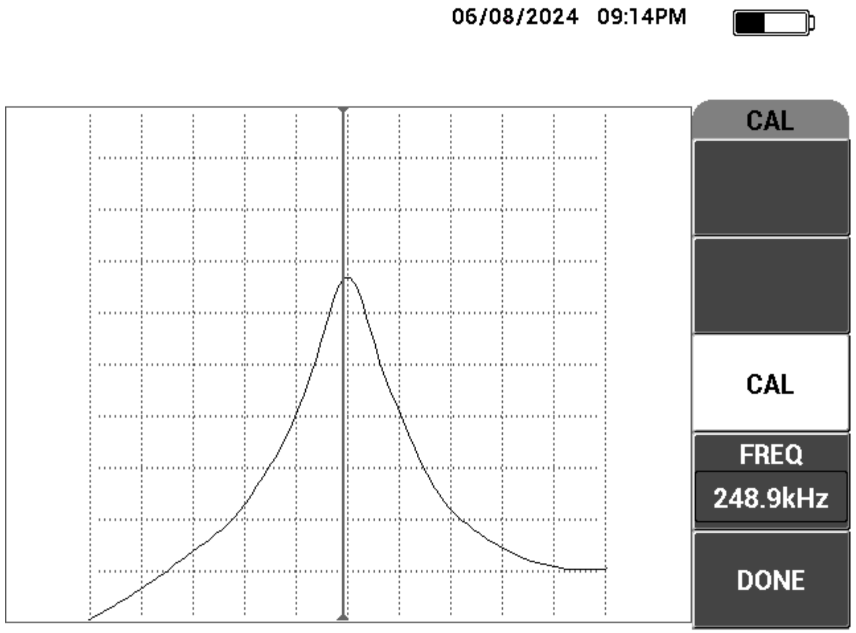


Resonance Testing Method

- Third engineered delamination in the test sample. The probe’s operating frequency is now 248.1 kHz. The resonance frequency is very close to the probe in air.

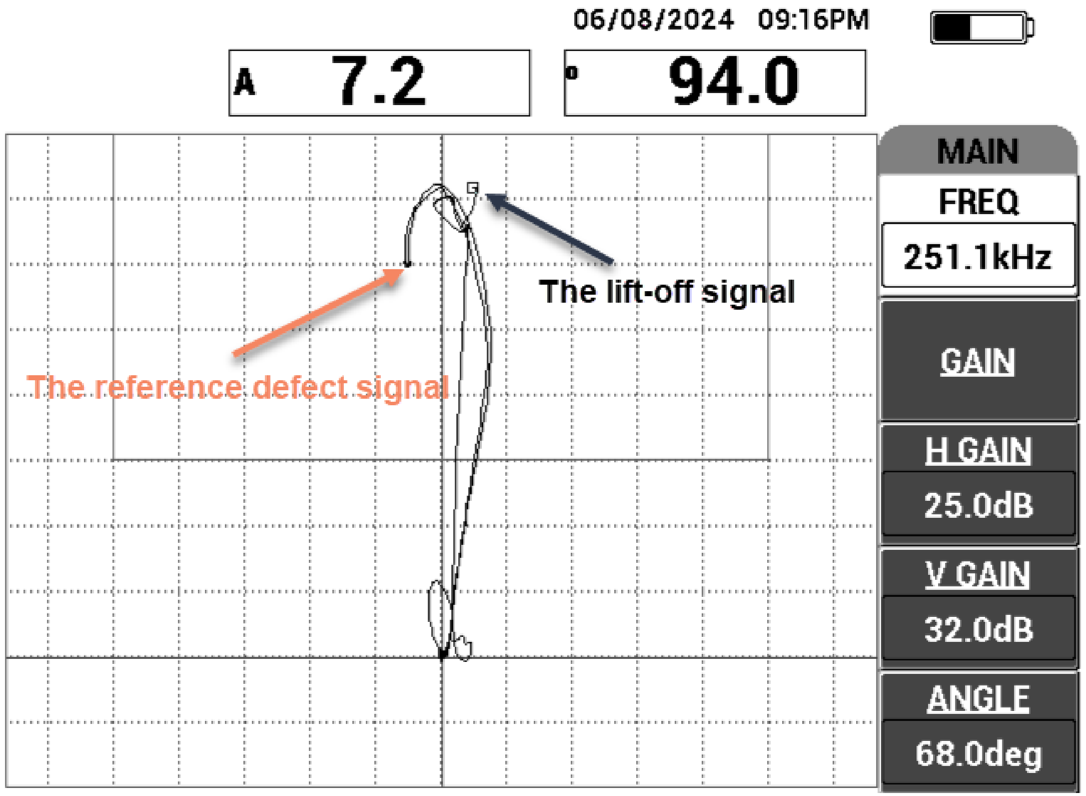


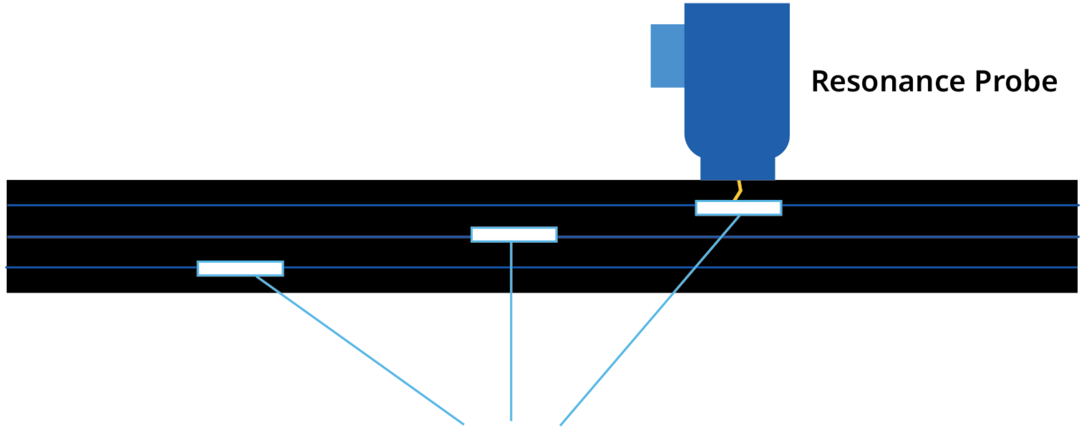




Resonance Testing Method

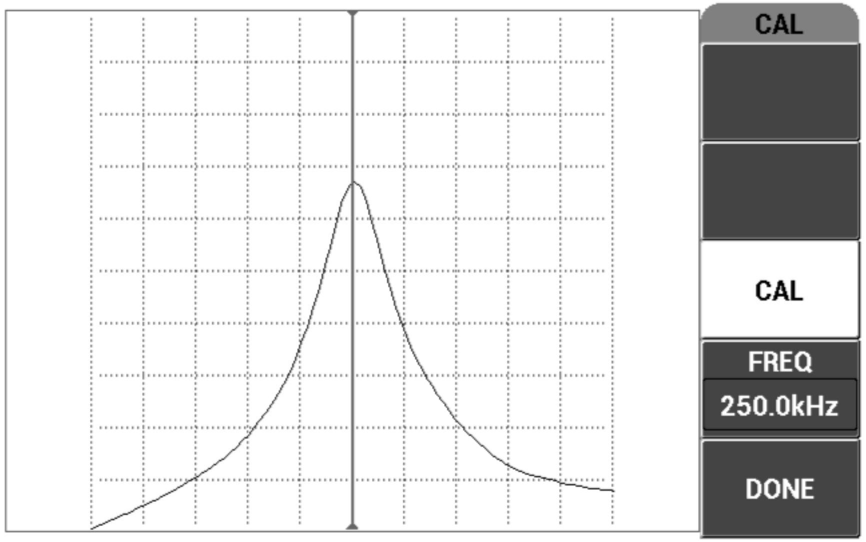
- Comparing the lift-off signal to the nearest engineered delamination to the surface, there is only a small distance between these two signals on the X/Y impedance plane. This should aid in signal interpretation to estimate the depth of a defect within a solid laminate structure.



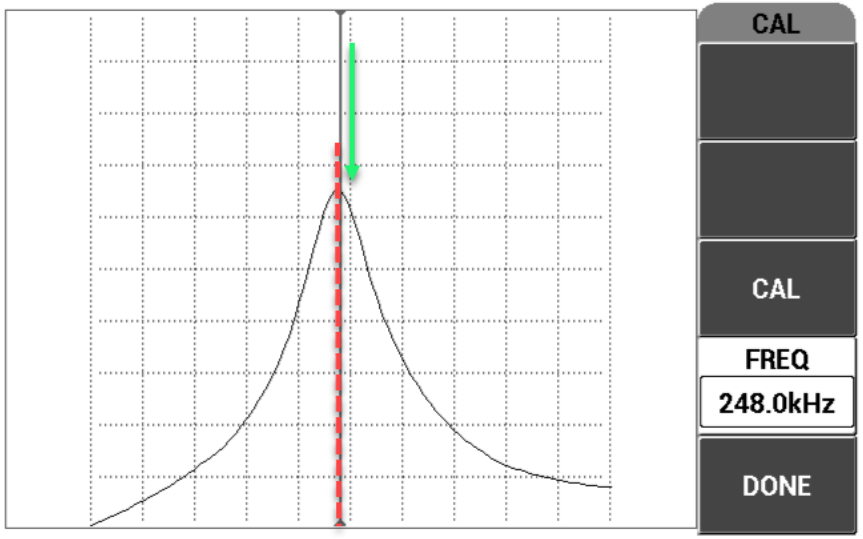


Resonance Testing Method

- Looking at the swept resonance frequency while the resonance probe is in air.
- The probe’s operating frequency is 250 kHz.

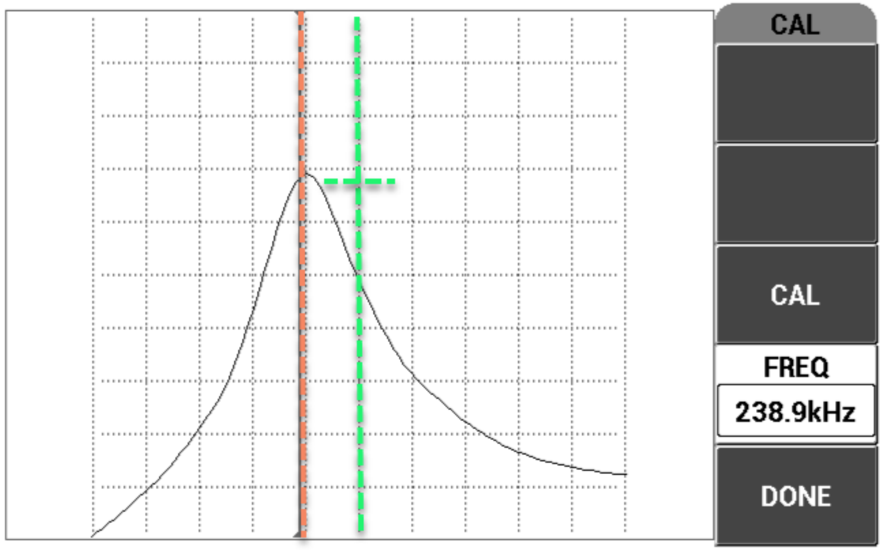


- The resonance probe is placed on 1-ply CFRP skin that is 0.008 in. (0.203 mm) thick. The swept frequency has only decreased in amplitude and phase slightly: 248 kHz.

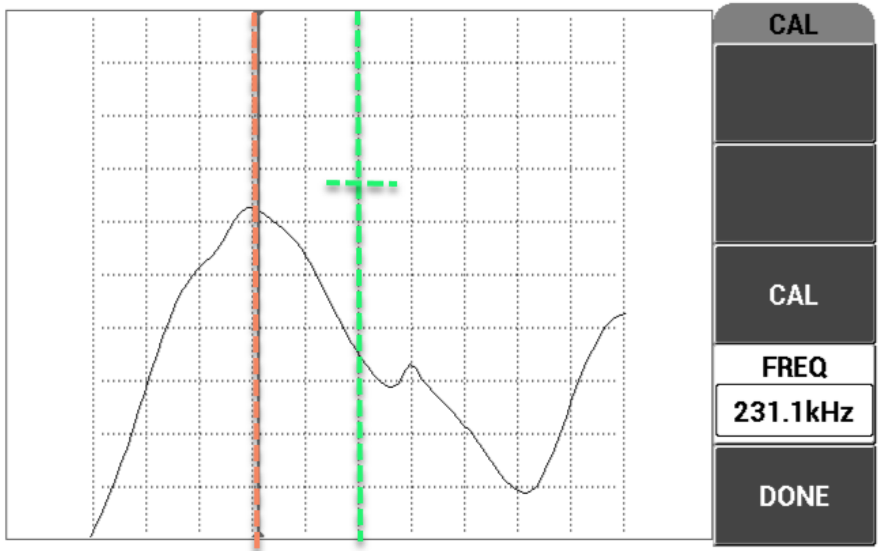


Resonance Testing Method

- The resonance probe is placed on 5-ply CFRP skin that is 0.040 in. (1.016 mm) thick. The swept frequency and phase have shifted. The frequency is now 238.9 kHz.



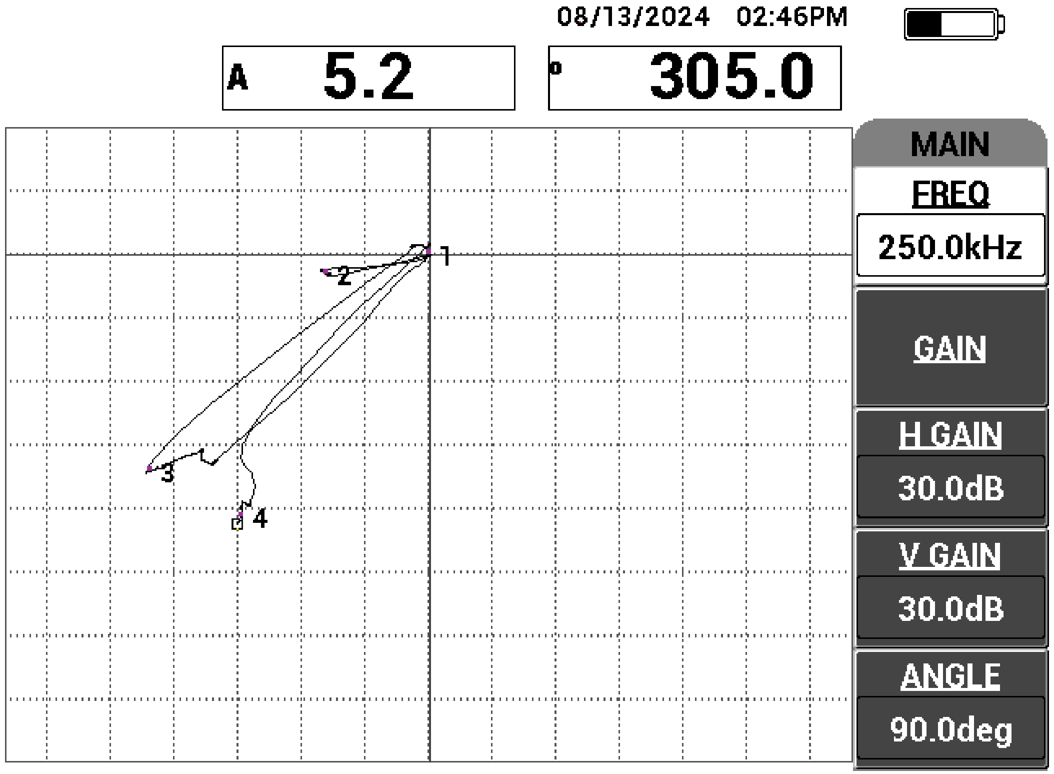
- The resonance probe is placed on 10-ply CFRP skin that is 0.080 in. (2.032 mm) thick. The swept frequency phase and amplitude have shifted. The frequency is now 231.1 kHz.



Resonance Testing Method

- Looking at the BondMaster 600 instrument's X/Y impedance plane display:
  - Signal marker #1: the probe in air.
  - Signal marker #2: the probe on 1-ply CFRP skin.
  - Signal marker #3: the probe on 5-ply CFRP skin.
  - Signal marker #4: the probe on 10-ply CRFP skin.

- Little distance between the probe balanced in the air compared to the probe on one ply of CFRP skin.
- Less mass loading compared to signals 3 and 4, where there is more mass loading on the probe, greatly influencing the probe's resonance frequency.

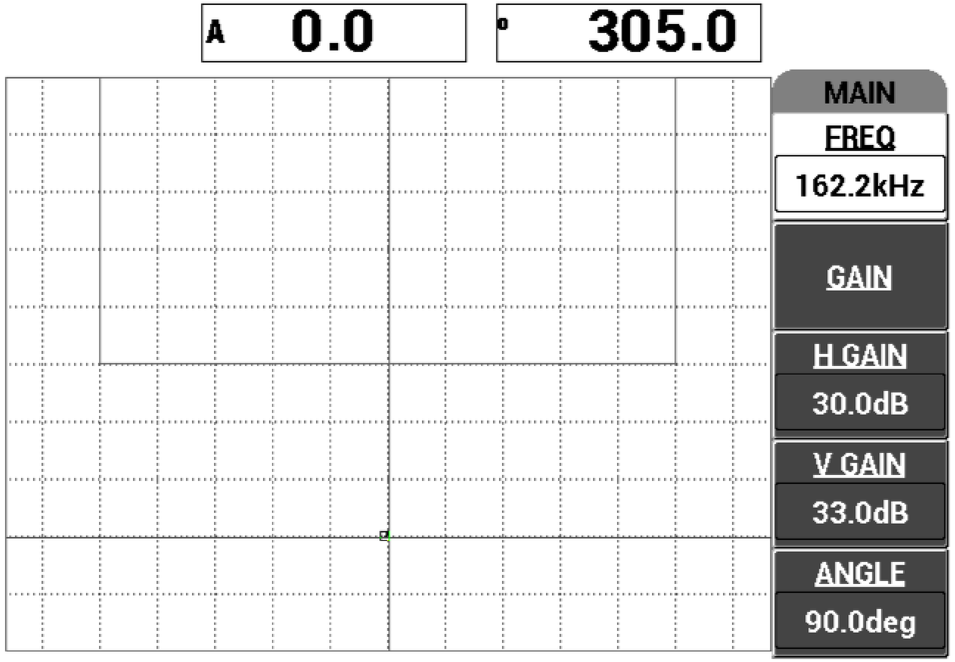


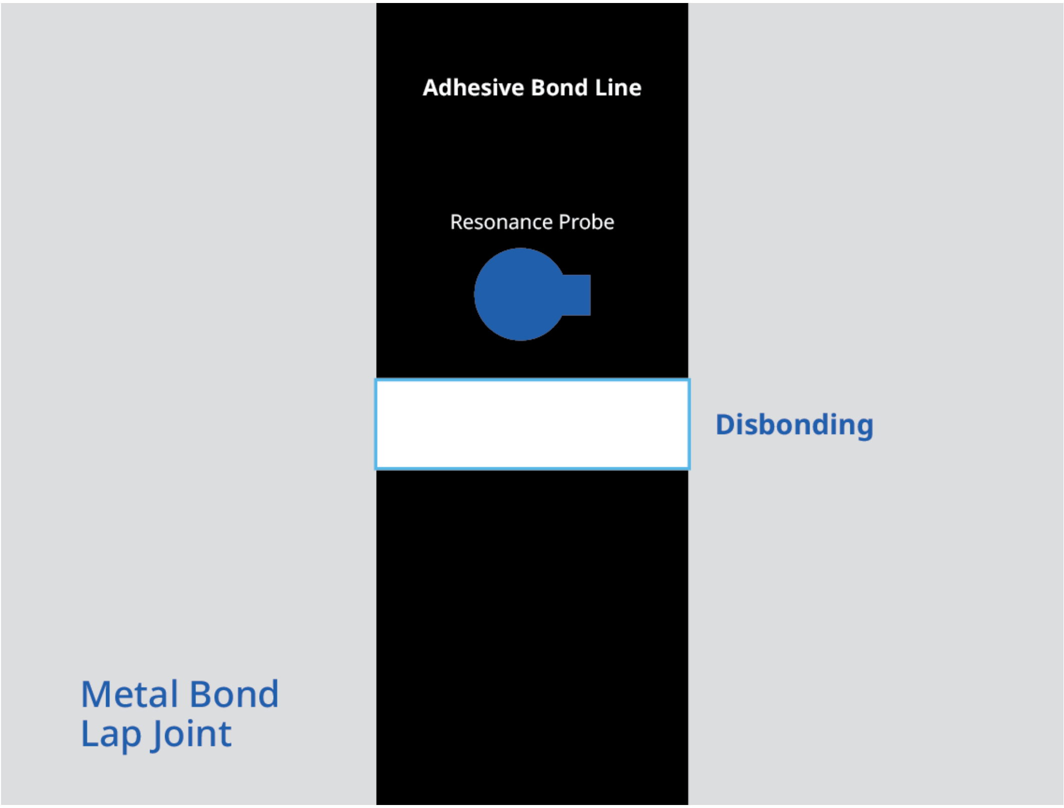
Resonance Testing Method

- An example of resonance testing to examine an aluminum-bonded lap joint test standard. For this examination, we will employ a 165 kHz probe.

The resonance probe in air.

The probe on the bonded lap joint.

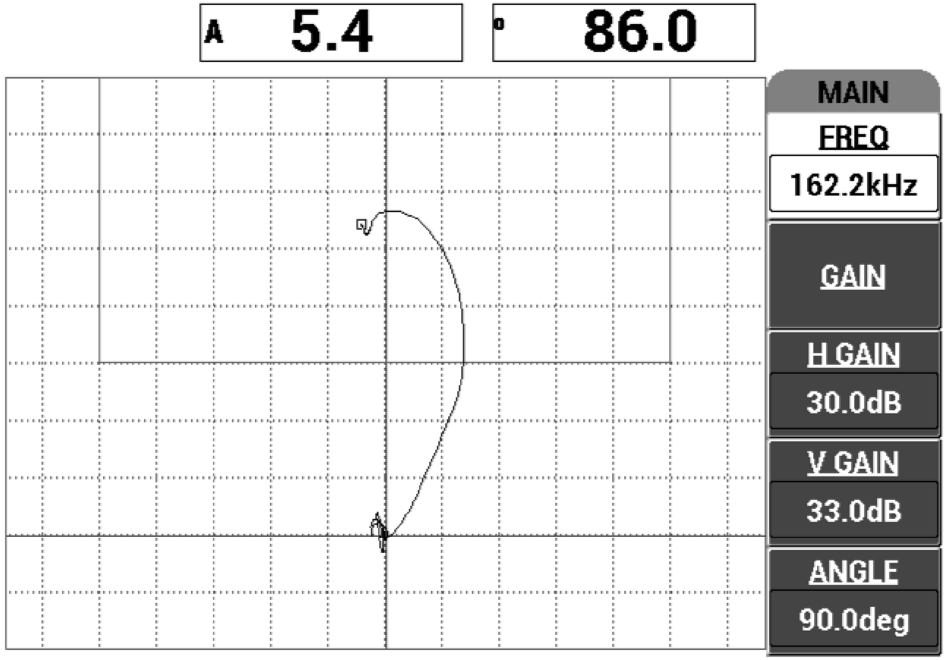


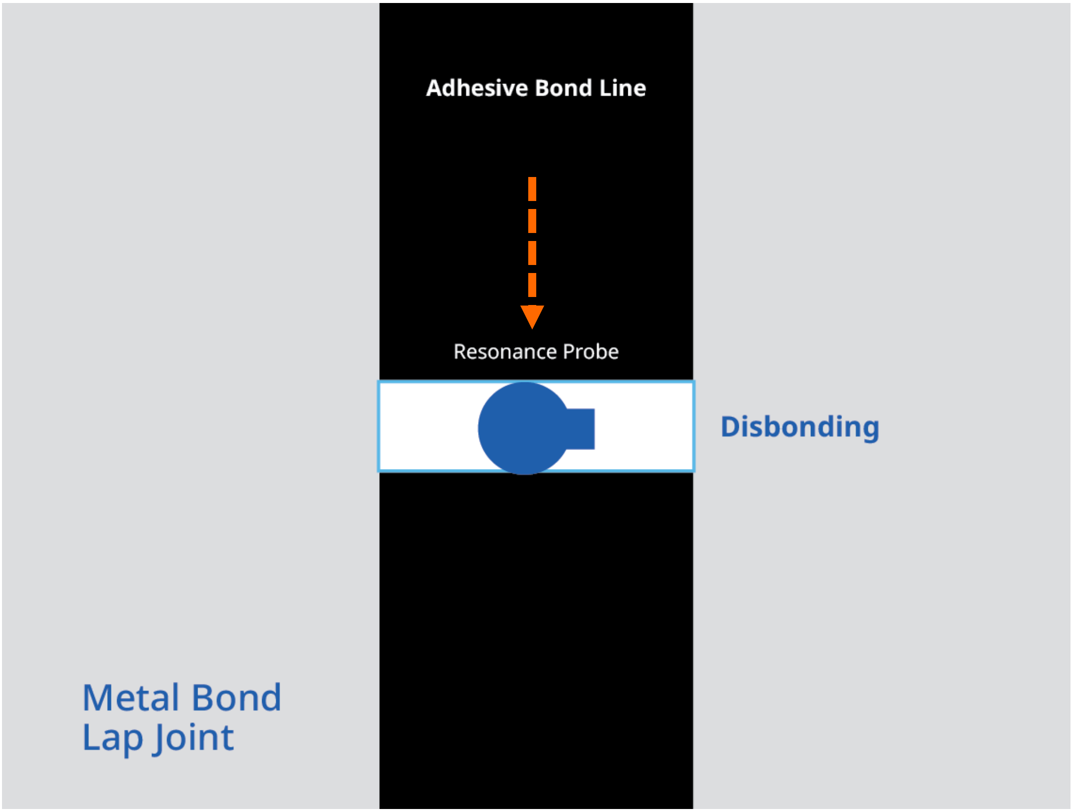


Resonance Testing Method

- Resonance testing to examine an aluminum-bonded lap joint test sample.

The probe over the disbonded joint.

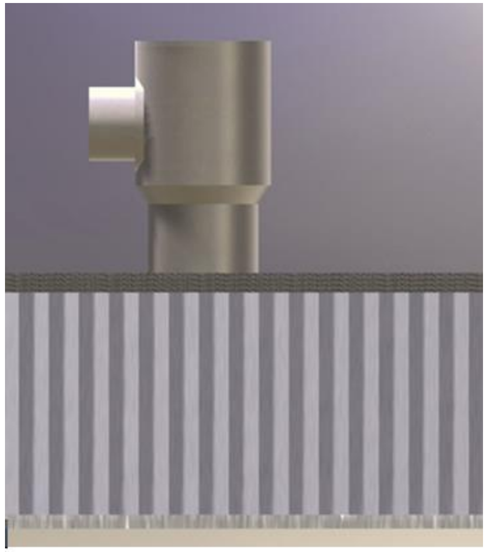




Resonance Testing Method

- While the resonance probe is resonating at its fixed frequency, as it is placed in contact with the test material, the tested material will “mass load” the probe. Two things happen when the probe contacts the test material:
  - The first is a damping effect on the piezoelectric crystal. Damping is defined as the physical restriction of oscillatory motion.
  - The second is a frequency shift from the null or “in air” resonant frequency. The electrical impedance varies with frequency and is lowest when the resonance probe is driven at its resonant frequency.

- As the resonance probe is placed on the material to be tested, the material’s mechanical impedance dampens the probe, and the probe’s frequency alters, decreasing in frequency along with amplitude and phase shift.

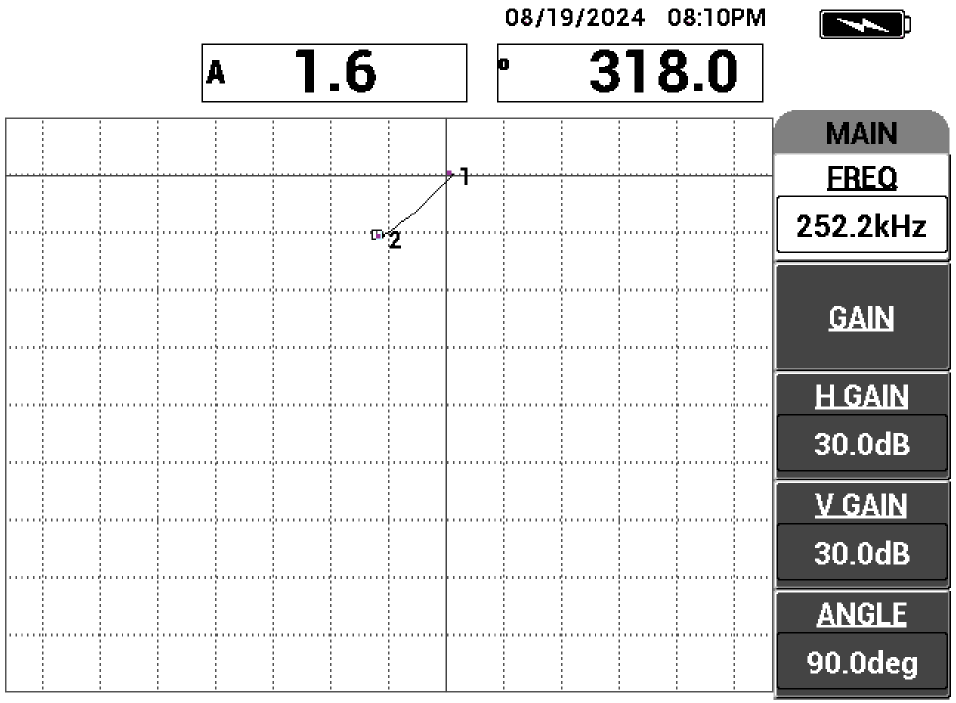


Resonance Testing Method

- Comparing ultrasonic to bond testing. In general, ultrasonic is the primary inspection on composite parts and structures.
- A side-by-side test comparison between ultrasonic and bond testing on a CFRP stepped solid laminate test sample from 1 to 9 plies. This test sample was cured at 45 pounds per square inch (PSI).

The comparable signal on 1-ply CFRP skin with a nominal thickness of 0.008 in. (0.203 mm).

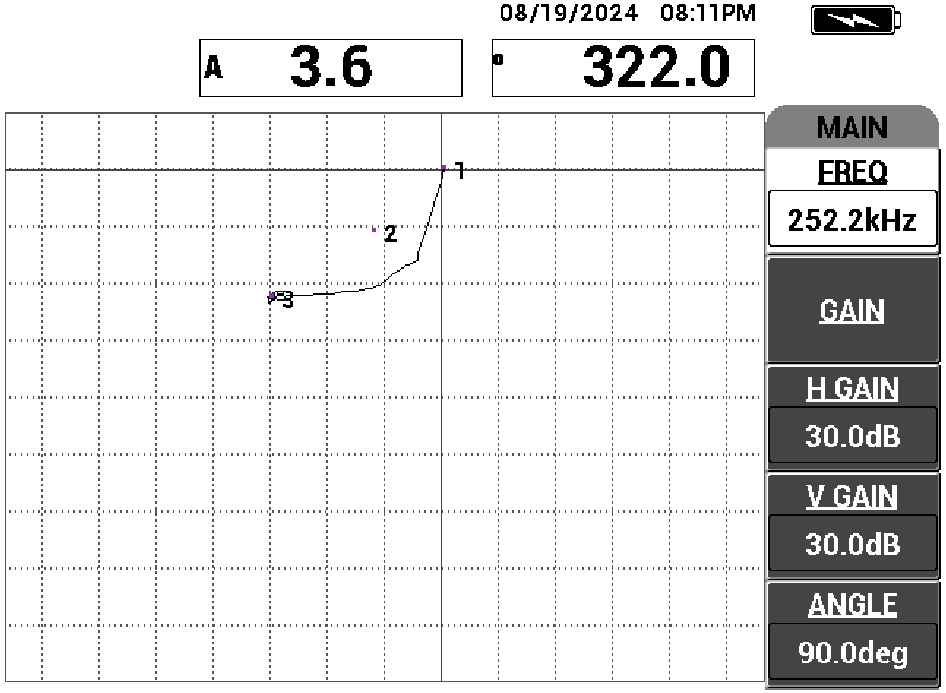
The instrument is set up for time-corrected gain (TCG).



Resonance Testing Method

- Side-by-side comparison results: ultrasonic to bond testing on the CFRP sample.

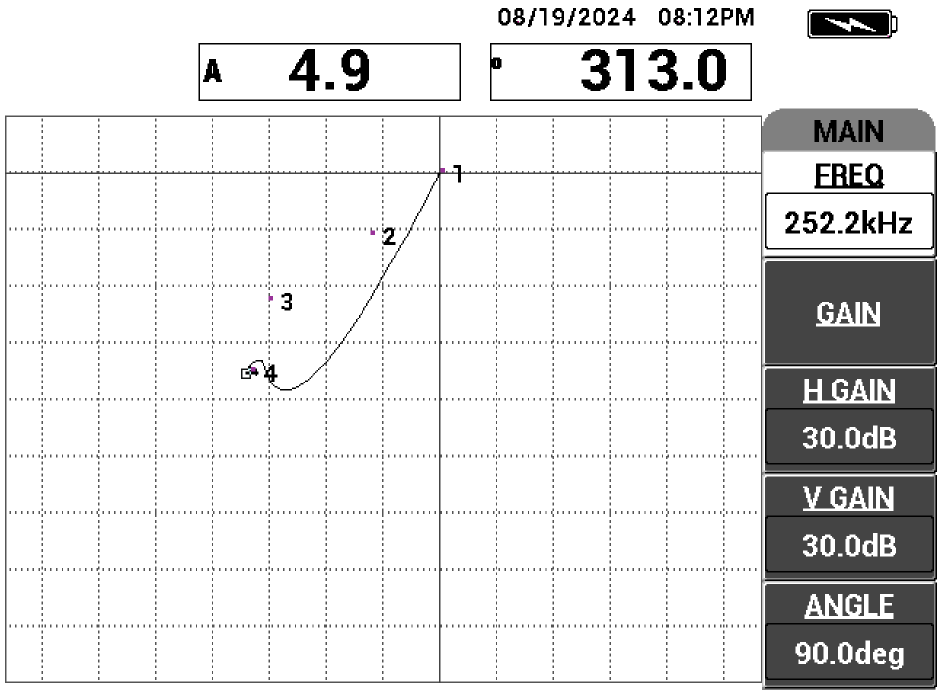
The comparable signal on 3-ply CFRP skin with a nominal thickness of 0.024 in. (0.609 mm).



Resonance Testing Method

- Side-by-side comparison results: ultrasonic to bond testing on the CFRP sample.

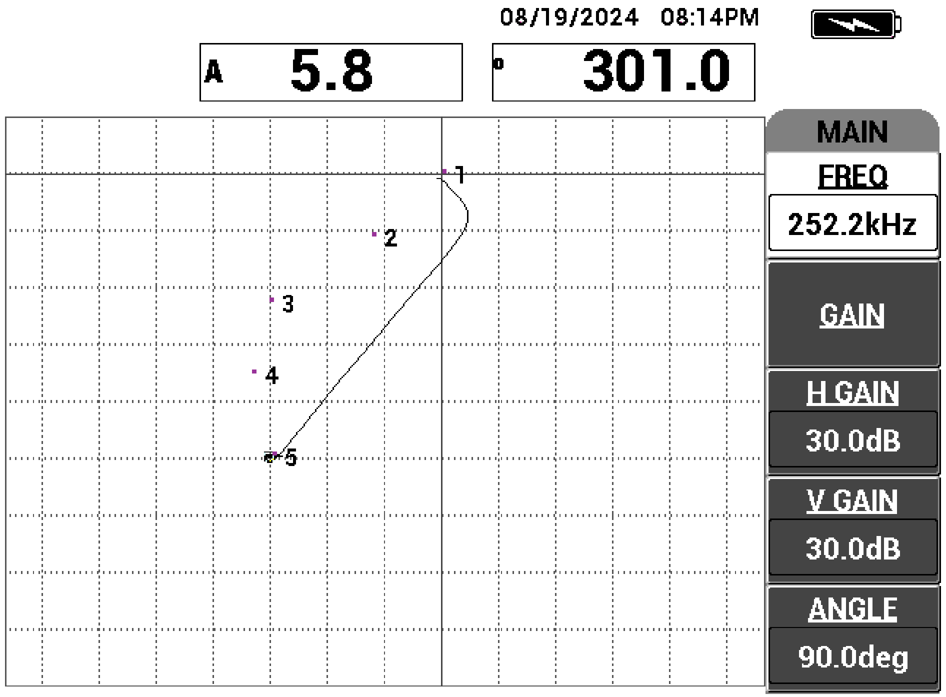
The comparable signal on 5-ply CFRP skin with a nominal thickness of 0.040 in. (1.016 mm).



Resonance Testing Method

- Side-by-side comparison results: ultrasonic to bond testing on the CFRP sample.

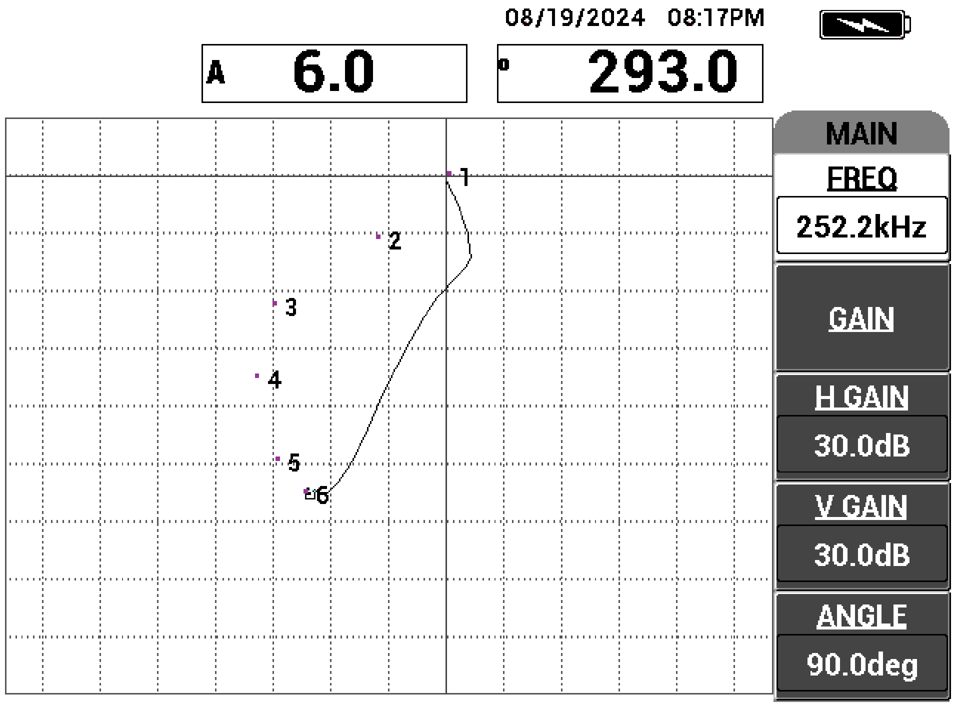
The comparable signal on 7-ply CFRP skin with a nominal thickness of 0.056 in. (1.422 mm).



Resonance Testing Method

- Side-by-side comparison results: ultrasonic to bond testing on the CFRP sample.

The comparable signal on 9-ply CFRP skin with a nominal thickness of 0.072 in. (1.422 mm).

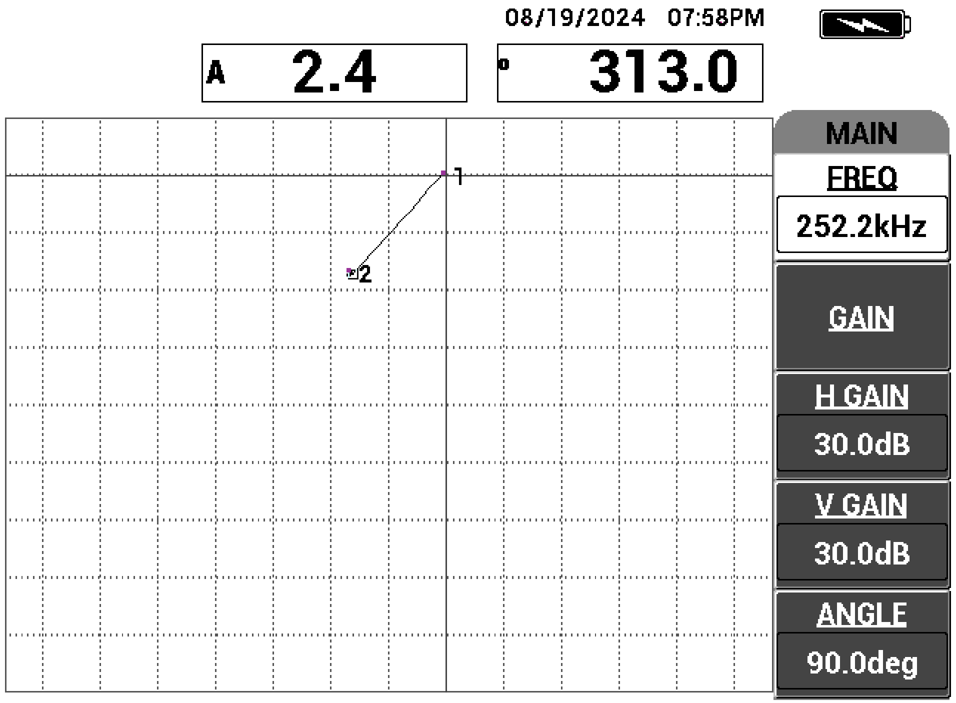


Resonance Testing Method

- A side-by-side comparison between ultrasonic and bond testing on a CFRP stepped solid laminate test sample from 1 to 9 plies that was cured at 12 PSI.

The comparable signal on 1-ply CFRP skin with a nominal thickness of 0.008 in. (0.203 mm).

The instrument is set up for time-corrected gain (TCG).



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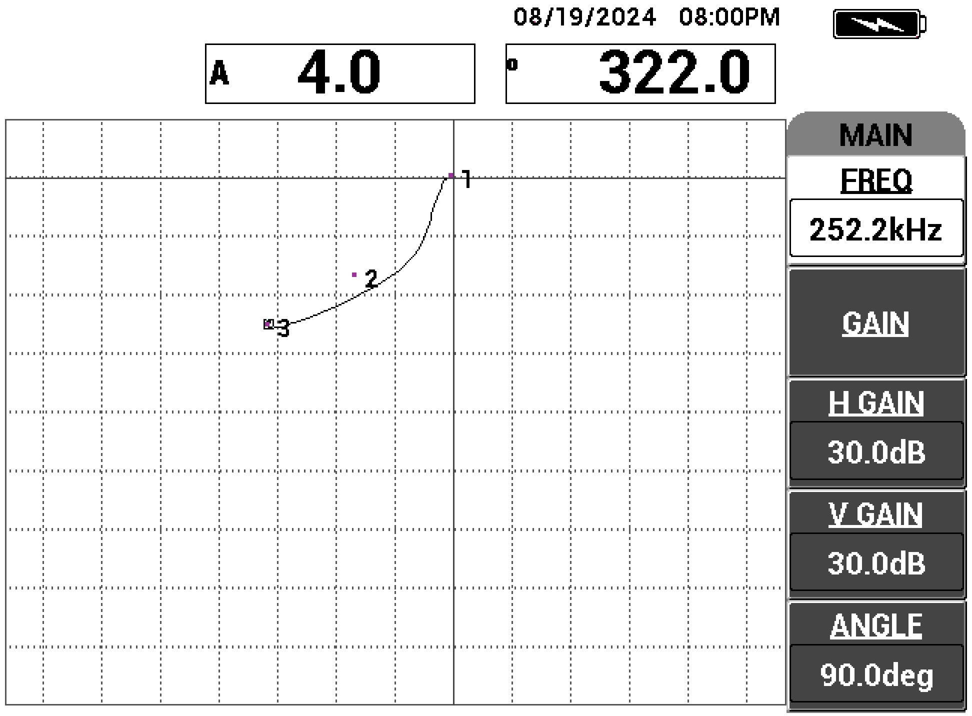

Resonance Testing Method

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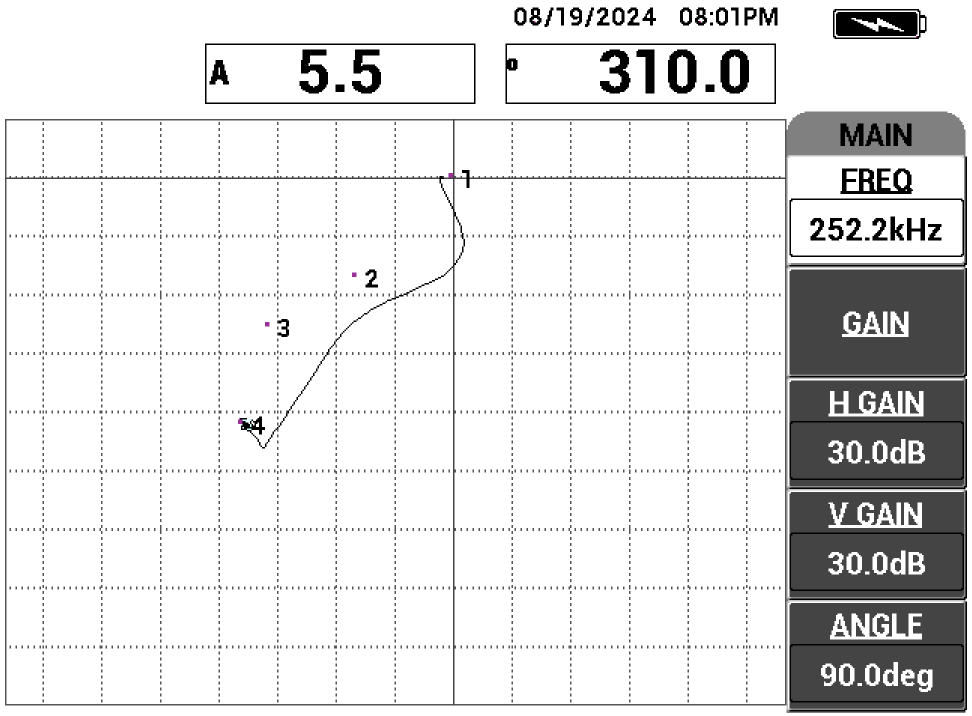

Resonance Testing Method

- Side-by-side comparison results: ultrasonic to bond testing on the CFRP sample.

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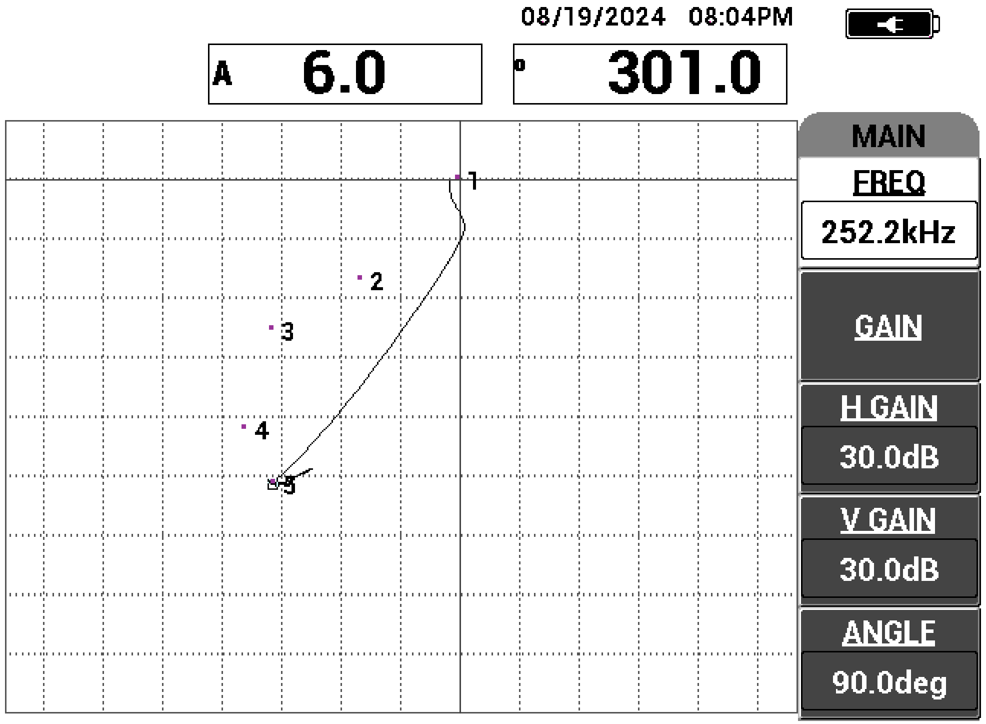

Resonance Testing Method

- Side-by-side comparison results: ultrasonic to bond testing on the CFRP sample.

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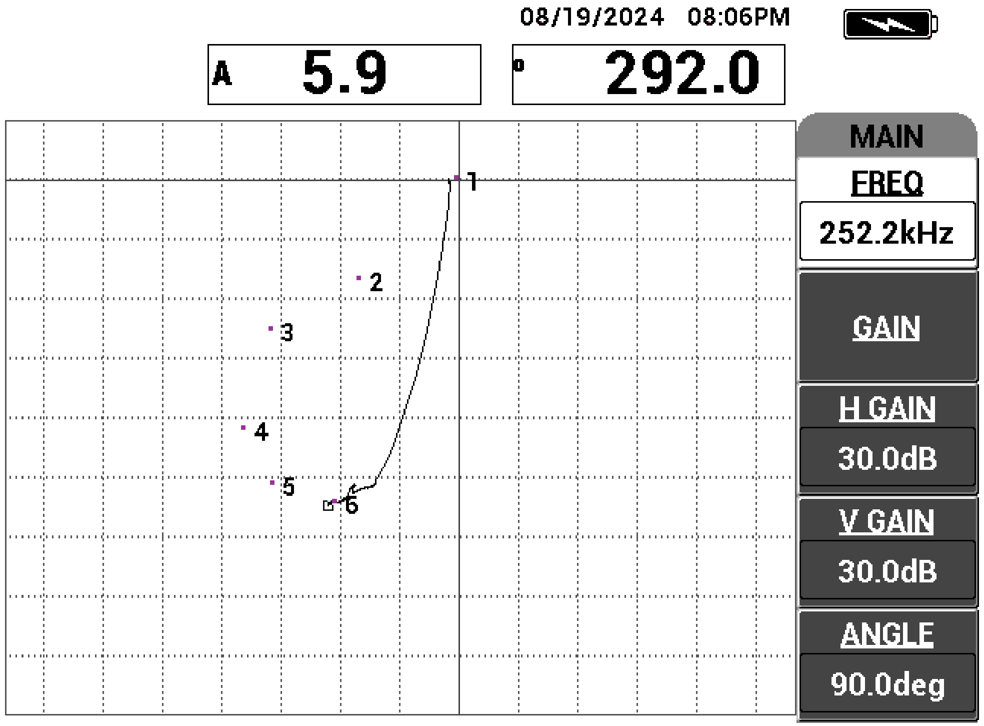


Resonance Testing Method

- Side-by-side comparison results: ultrasonic to bond testing on the CFRP sample.

Side-by-side resonance testing results: CFRP 45 PSI vs. 12 PSI

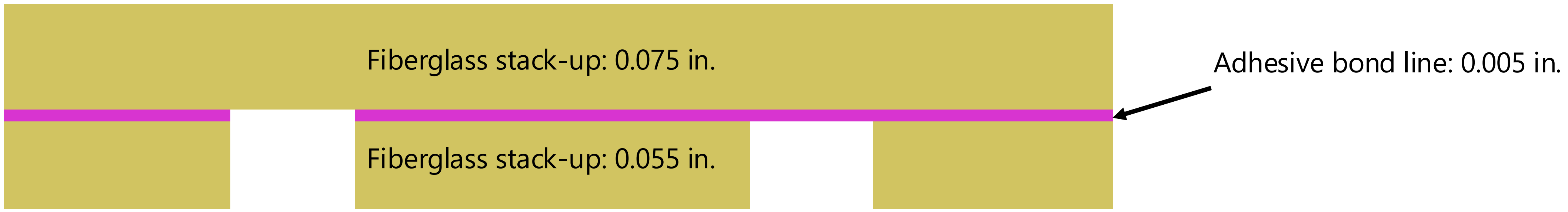
Side-by-side ultrasonic testing results: CFRP 45 PSI vs. 12 PSI at 9 plies

45 PSI

12 PSI

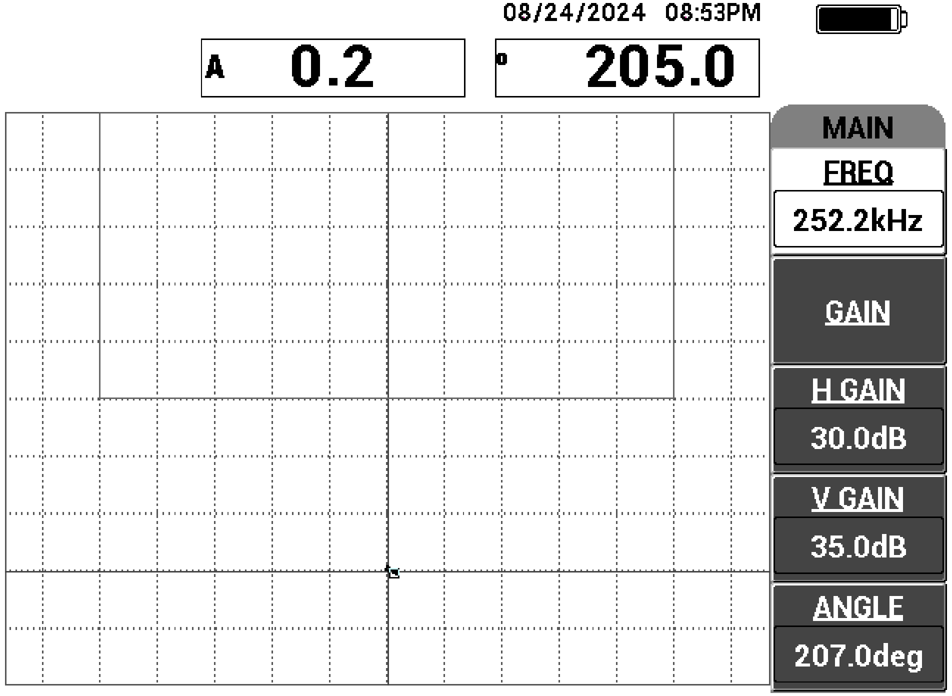
Resonance Testing Method

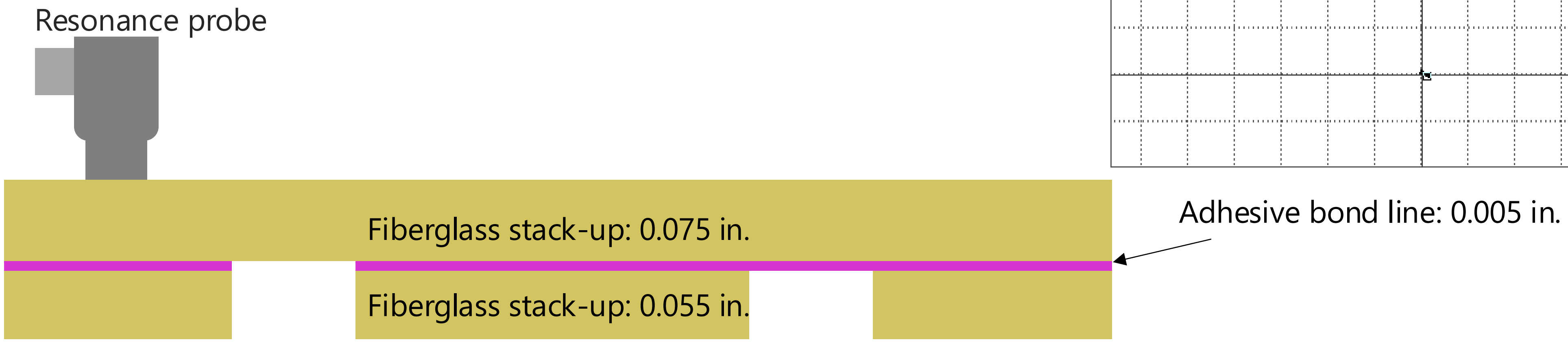
- How accurate is resonance testing? It greatly depends on the overall construction of the test material, the defect type and size, and the probe selected for the inspection.
- The below test sample is a fiberglass skin section bonded together with two milled pockets to simulate bond line disbonding. The critical difference between the two milled pockets is the 0.005-inch (0.127 mm) bond line.



Resonance Testing Method

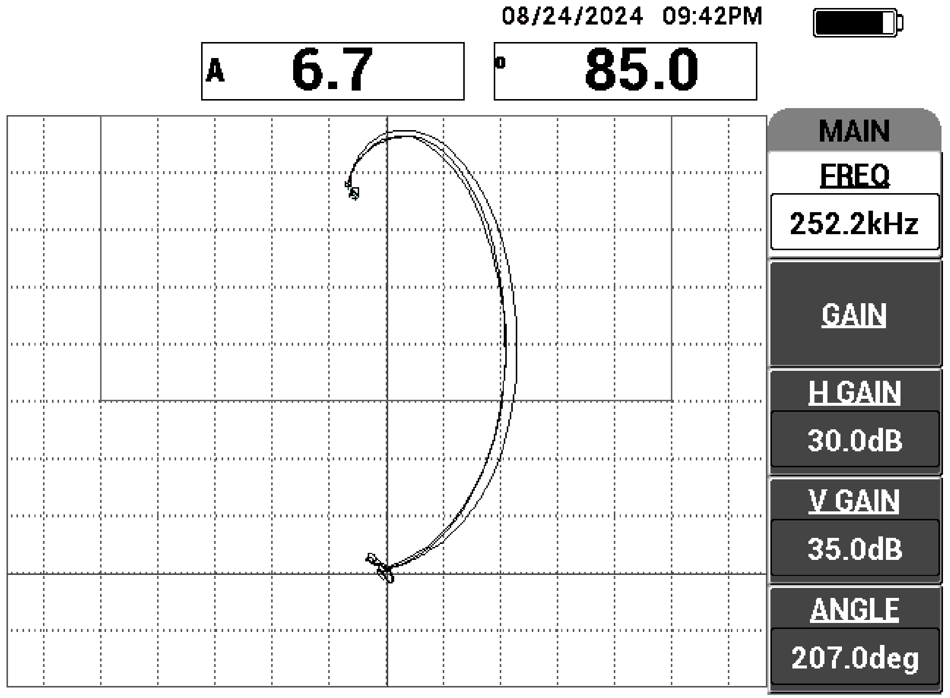
- Test results from the fiberglass sample with two milled pockets.
    - The probe balanced on the test sample.



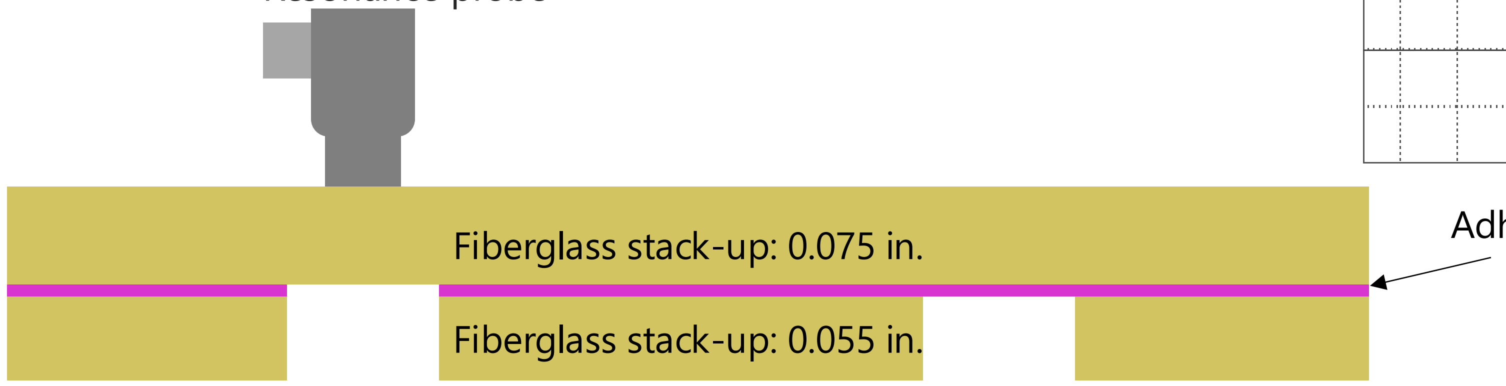


Resonance Testing Method

- Test results from the fiberglass sample with two milled pockets.
  - The probe over the first milled pocket.



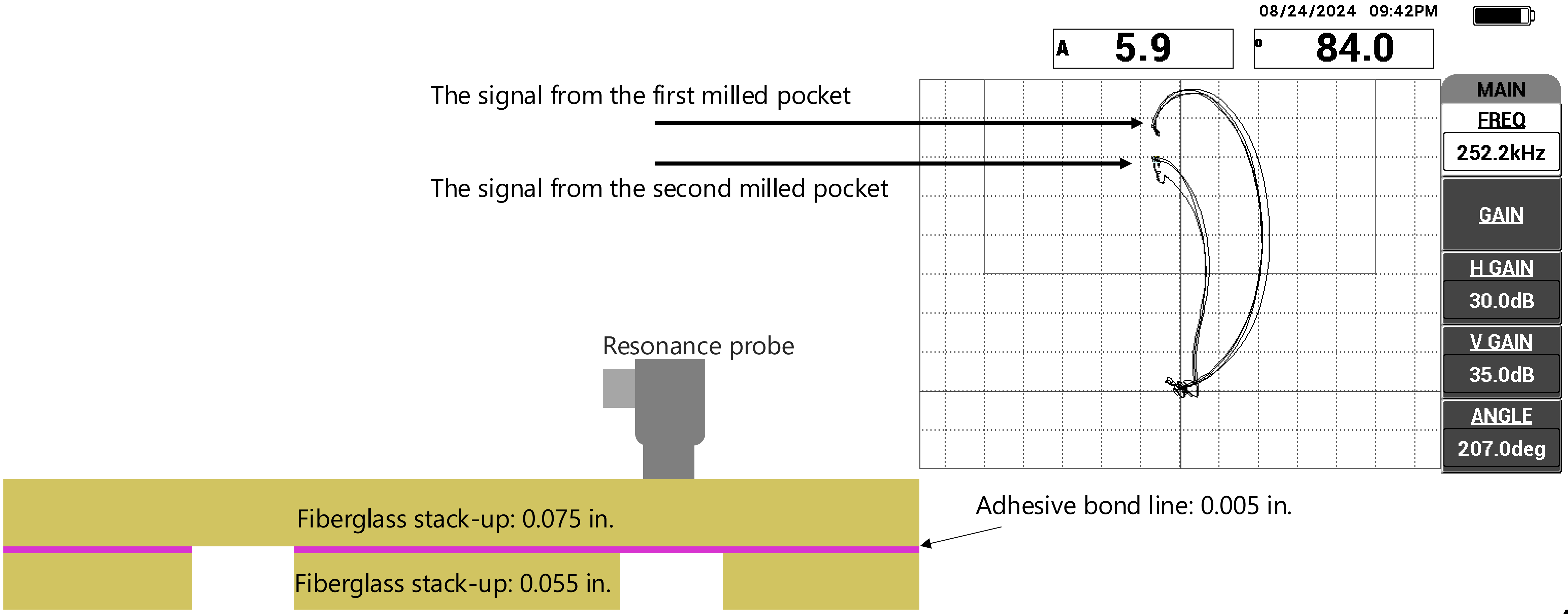
Resonance probe



Adhesive bond line: 0.005 in.

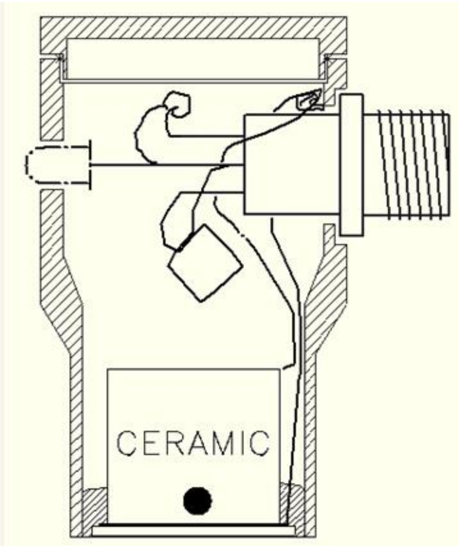
Resonance Testing Method

- Test results from the fiberglass sample with two milled pockets.
  - The probe over the second milled pocket.



Resonance Testing Method

- The most common failures with resonance probes are related to wear and tear.
- Common items within a resonance probe that can lead to failure:
    - Broken wires
    - Ceramic delamination
    - Worn, delaminated, wear or damaged element

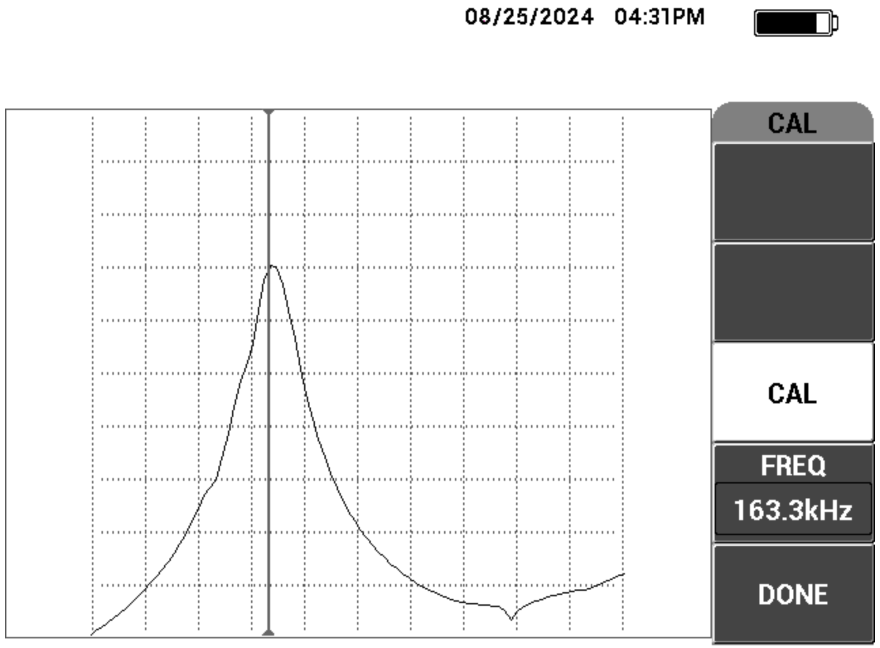


Resonance Testing Method

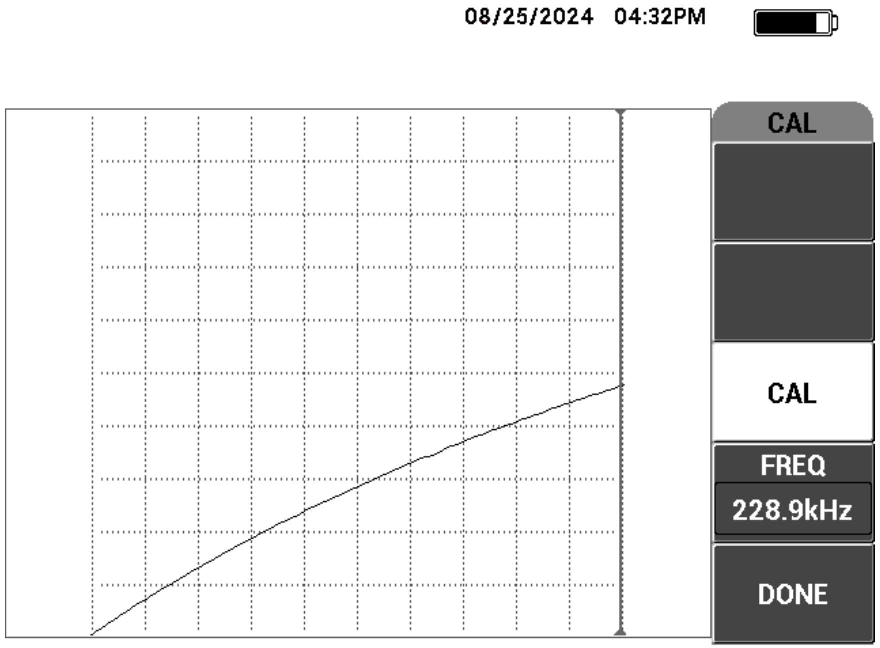
Probe wear

- Set frequency for the S-PR-4 resonance probe is 165 kHz (+/- 10 kHz).
- An out of frequency range may be due to a broken or delaminated element, a broken wire, or a short in the wire.

Probe pass calibration



Probe failed calibration



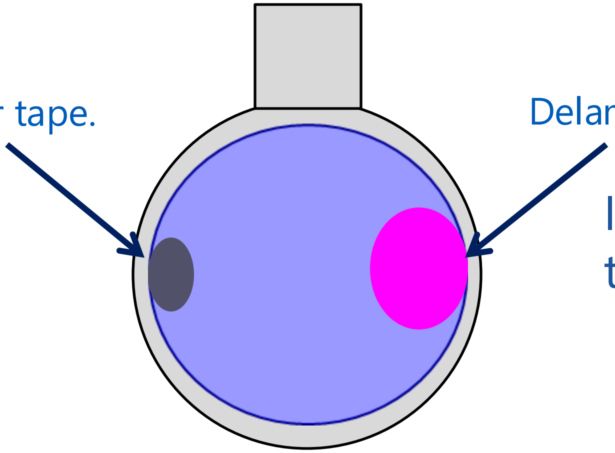
Resonance Testing Method

Probe wear

- A bubbling in the wear face could indicate that the element is delaminating from the ceramic.
- Or couplant is getting in between the element and the Teflon wear tape.

Couplant between the element and the wear tape.

Delamination between the element and ceramic backing.



If in dough, suggest replacing the Teflon tape on the face of the probe.

- Both will influence the signal on the screen and make it difficult to analyze the information on the screen.

Conclusion

Key takeaways on resonance bond testing:

- Not to be confused with resonant testing performed on metal parts, where natural whole-body frequencies are analyzed.
- It is different than ultrasonic testing.
- It is where there is a damping effect (mass loading) on the probe’s resonance frequency.
- It is a comparative test method.
- It requires detailed standards for calibration and analyzing the signals on the screen.

References

ASNT ~ June 2021 Edition of Martial Evaluations Resonance Bond Testing: Theory and Application.
By Stetson S. Watkins

Evident ~ InSight Blog: Evaluating CFRP Automotive Parts with Bond Testing: A Cost-Effective NDT Method.
By Betsy Kenaston
https://www.olympus-ims.com/insight/evaluating-cfrp-automotive-parts-with-bond-testing-a-cost-effective-ndt-method.

Botsco, R. J., Todd, J. E., & Jones, R. L., (1980). *U.S. Patent No. 4,215,583*. Washington, DC: U.S. Patent and Trademark Office.

Guyott, C. C. H., Cawley, P., & Adams, R. D. (1987). Use of the Fokker Bond Tester on Joints with Varying Adhesive Thickness. *Proceedings of the Institution of Mechanical Engineers, Part B: Management and Engineering Manufacture, 201(1)*, 41–49.

Guyott, C. C. H., Cawley, P., & Adams, R. D. (1986). Vibration characteristics of the Mk II Fokker Bond Tester probe. *Ultrasonics, 24(6)*, 318–324.

Evident (2016*). BondMaster 600 Composite Bond Tester: User's Manual.*
Retrieved from: https://www.olympus-ims.com/en/resources/manuals.

U.S. Department of Transportation/Federal Aviation Administration. (2016). *A Quantitative Assessment of Conventional and Advanced Nondestructive Inspection Techniques for Detecting Flaws in Composite Honeycomb Aircraft Structures* (Report No. DOT/FAA/TC-15/63). Atlantic City, NJ: William J. Hughes Technical Center, Aviation Research Division.

U.S. Department of Transportation/Federal Aviation Administration. (1994). *Evaluation of Scanners for C-Scan Imaging for Nondestructive Inspection of Aircraft* (Report No. DOT/FAA/CT-94/79). Atlantic City International Airport, NJ: Federal Aviation Administration, Technical Center.

Thank you for your attention

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