Frequency Considerations in Air-Coupled Ultrasonic Inspection.

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Abstract

Air-coupled Ultrasonics offers many potential advantages in terms of ease of use and compatibility with materials and processes. The method has been broadly separated into two areas: High frequency systems offering resolution comparable to conventional techniques, but suitable only for 'good' materials which are easy to penetrate, and lower frequency systems which can penetrate 'tougher' materials, but which offer limited ability to resolve material structure and smaller defects.

Work has continued to 'bridge the gap' by improving the penetration/resolution trade off. Meanwhile introduction of equipment capable of testing at several frequencies has permitted the development of new techniques. These compare results at different frequencies to allow more qualitative assessments of material 'defects' to be made. In particular it has been possible to distinguish between de-lamination (which blocks all frequencies) and porosity (which selectively attenuates higher frequencies)

1. Introduction

A Previous paper has discussed the Airscan technology in considerable detail, to recap briefly:

- Air is generally unsuitable as an ultrasonic couplant because of the poor acoustic match with typical material which it is required to inspect.

- This mismatch occurs at four interfaces: Probe-air – material – air – probe. (see figure 1)

- Typically this results in a loss of up to 30 dB per interface – i.e. a total path loss of up to 120 dB compared to a few dB when water is used as the couplant.

- The QMI Airscan technology achieves a usable inspection sensitivity, despite this problem, by a combination of techniques, in particular:

– A high power tone-burst pulser circuit.
– Resonant probe design
– High gain, low-noise amplification.

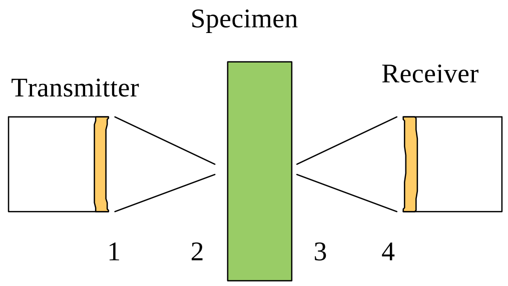


Figure 1: Losses at interfaces with Air-coupled UT


Figure 2: QMI Sonda 007CX system

Because of the huge ratio between incident and transmitted power levels Air-Coupled Ultrasound is normally only practical as a dual probe, through transmission technique, producing amplitude only data. For most applications a scanning mechanism and suitable C-scan Software is required for interpretation of results.

Figure 3: QMI LS-12 scanner

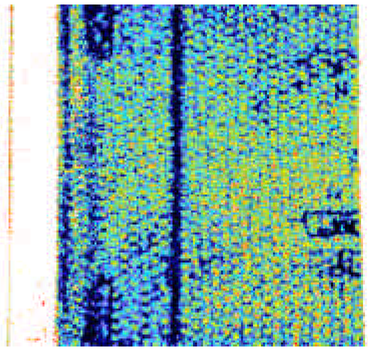


Figure 4: C-scan image of composite assembly

2. Experience with Air-coupled Ultrasonics at Medium Frequencies

Until recently the majority of work carried out by QMI has been at medium frequencies (400kHz) This has proved very successful for C-scan ultrasonic testing of composite laminates, honeycomb structures, circuit boards, as well as for process control in pultrusion manufacturing.

Compared to the frequencies of 1 MHz and higher used in most contact ultrasonic applications, the 400 kHz of the air-coupled technique may be considered relatively low. Nevertheless, a lateral resolution of about 0.040 in. (1 mm) is achieved, due to the focusing effect of the air-coupled transducers. Such resolution has proven more than adequate for virtually all applications.

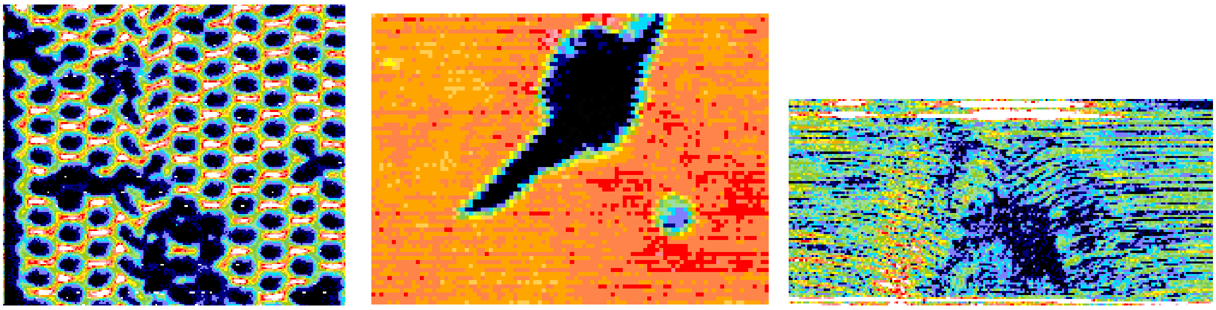


Figure 5: Typical Results from 400 kHz Air-coupled Inspection :
a) Honeycomb b) Carbon composite impact test c) Wood

3. The need for greater penetration

The aircraft industry is using more and more highly attenuative materials, such as foam sandwich structures and multiple layer honeycombs. It is often impossible to penetrate most of these materials using frequencies of 400 kHz and higher. This has brought new challenges to the testing instrumentation. The main losses of foam material are very likely caused by beam scattering. Such losses are known to depend strongly on the frequency and increase with the fourth power of the frequency. It can therefore be expected that by using ultrasonic frequencies which are even lower than 400 kHz, it might be possible to penetrate through foam structures.

The Sonda 007 Instrument has been modified to drive 50 kHz electrostatic transducers.
The electrostatic transducers are flat, with a diameter of 38mm. They have a transmit and receive response which varies within 10 dB between 50 and 100 kHz, and a beam angle of about 30 degrees.

Various configurations of the 50 kHz transducers were investigated. (Figure 6) In the through-transmission configuration, both transducers were mounted to produce a beam perpendicular to the surface and at a distance of 70 mm. In a quasi “focused” configuration the transducers in the through-transmission configuration were displaced laterally, so that that the ultrasonic beam was only marginally intersected by the receiver

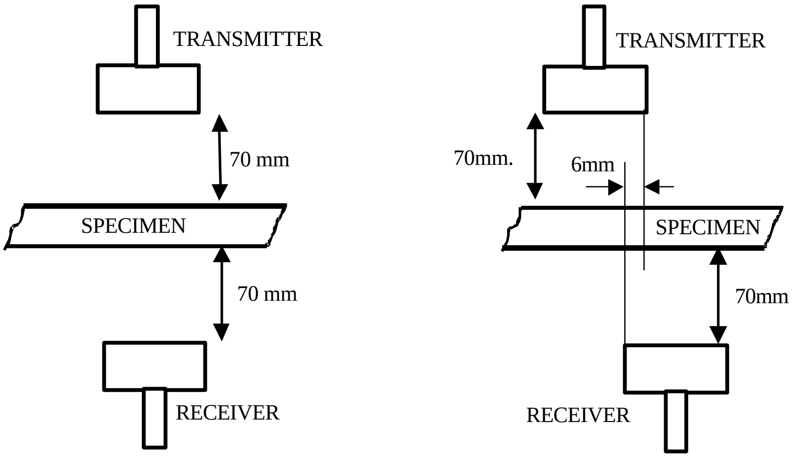


Figure 6: 50 kHz transducers:

a) In through-transmission

b) In 'displaced' through-transmission

4. Assessment of Lateral Resolution of 50 kHz techniques

A thermoset carbon fiber composite panel, measuring 50cm square, having a thickness of 6mm, with artificially built in defects was scanned using various techniques. The artificial defects consisted of teflon inserts, measuring from 1.6mm. to 20mm in diameter. These inserts were 10cm apart and arranged in a 5 x 4 grid. All scans were performed at a speed of 150mm/sec, with a step size of 0.75mm.

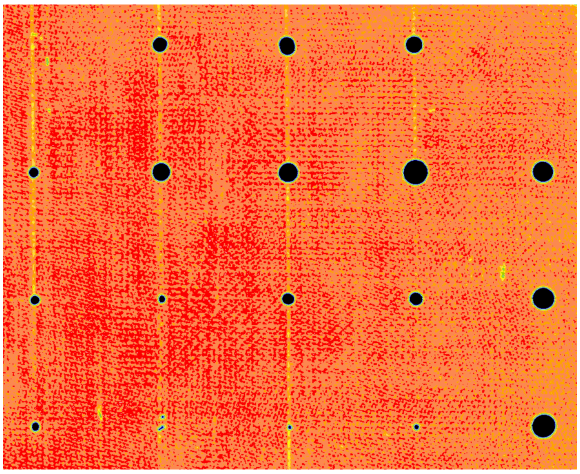


Figure 7: C-scan image with water squirters at 2.25 MHz. Teflon inserts measuring 1.6mm to 20mm at 100mm. Distances.

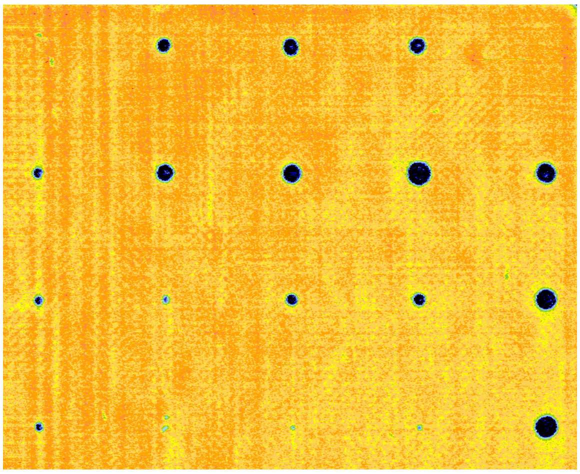


Figure 8: C-scan image with 400 kHz air-coupled transducers. The smallest resolved Teflon inserts in the bottom row measure 1.6mm. in diameter.

The first scan was used to establish a baseline and was performed using water squirters and 2¼ MHz transducers. The resulting C-scan image is shown in figure 7. The smallest inserts, are resolved in column 2, 3, and 4 of row 4.

Figure 8 shows a C-scan image performed with the resonant air coupled and focused transducers at 400 kHz in through transmission. Note that despite the lower contrast and the lower frequency, the smallest Teflon inserts in row 4 can still be detected.

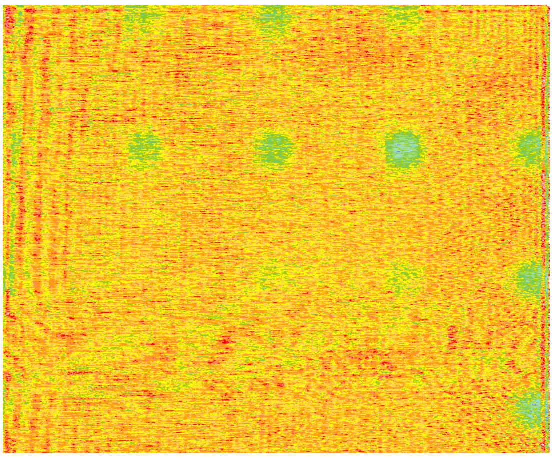


Figure 9: C-scan image with 50 kHz transducers in straight through-transmission. Teflon inserts with diameters less than 12 mm. cannot be resolved.

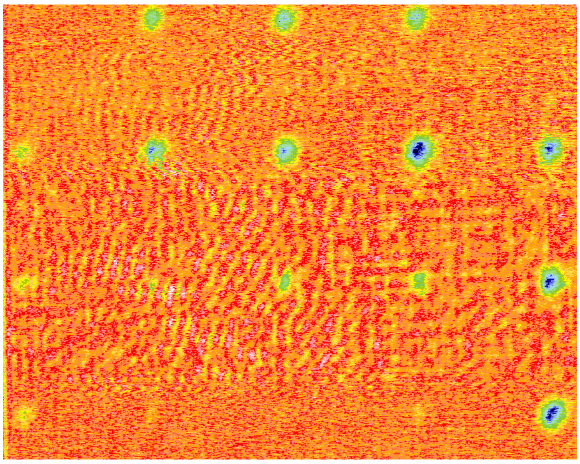


Figure 10: C-scan image with 50 kHz transducers, laterally displaced, in through-transmission. Teflon inserts with diameters less than 8 mm. cannot be resolved.

The C-scan image shown in figure 9 was performed with the 50 kHz transducers in through transmission, aligned as shown in figure 6a. As can be expected, due to the large diameter of these transducers and to the low frequency, the lateral resolution is significantly less than in the previous scan. The inserts of 12mm in diameter in the top row are at the limit of resolution. The largest insert of 20mm in diameter is clearly resolved, which is still only half the transducer diameter.

For the C-scan of figure 10, the 50 kHz transducers were laterally displaced as shown in figure 6b, where the receiver captures only a small part of the transmitted ultrasonic beam. The result is improved resolution and higher contrast: 8mm. inserts in row 3 can be resolved.

5. Frequency dependant transmission

Two carbon-carbon silicon carbide (SiC) coated panels having a thickness of 3mm, which were fabricated during an R&D stage, were tested ultrasonically with air-coupled transducers at two different frequencies. The C-scans were performed at a speed of 150mm/sec, with a step size of 0.75mm

Figures 11 & 12 show two C-scans from a 15 x 20 cm section of a Silicon carbide coated panel. The C-scan of figure 11 was produced using the 400 kHz focused transducers, while the C-scan of figure 12 was produced with the 50 kHz electrostatic unfocused transducers.

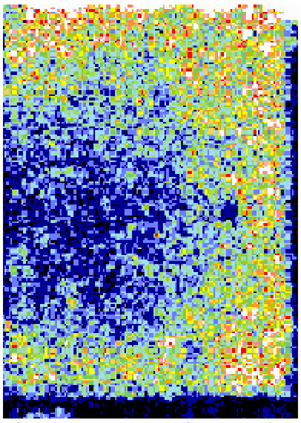


Figure 11: C-scan image of a 15 x 20 cm.. section of a SiC panel scanned with 400 kHz air-coupled transducers.

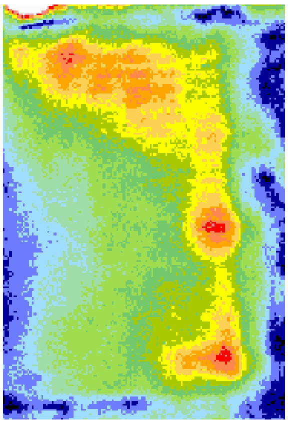


Figure 12: C-scan image of a 15 x 20 cm.. section of a SiC panel scanned with 50 kHz air-coupled transducers.

Note the dark blue area in the centre of figure 11 Such an area could be indicative of intermittent voids. The same area, however, appears much lighter and green in figure 12. It follows from the applied colour code, that the dark blue area of figure 11 has a transmission of about 10% of the maximum amplitude (white spots), while the same area in figure 12 has a transmission amplitude of about 25% of the maximum transmitted amplitude (dark red spots). Such a frequency dependant transmission is indicative of an increased porosity rather than of intermittent voids. The increased porosity was subsequently confirmed through destructive testing.

Another development panel, measuring 15cm. by 30cm, was also scanned twice, first at 400 kHz, and then at 50 kHz. The C-scans are shown in figures 13 & 14.

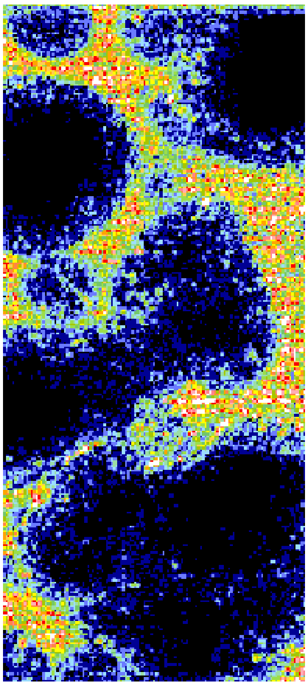
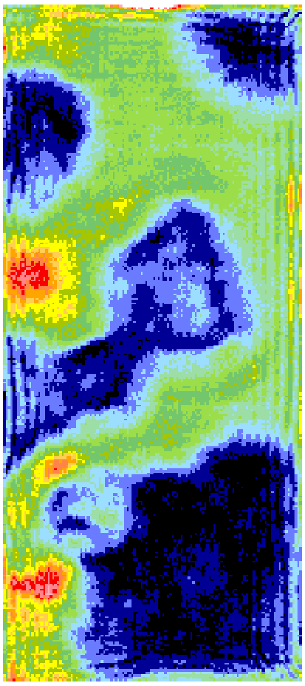




Figure 13: C-scan image of a 15 x 30 cm. section of a SiC panel scanned with 400 kHz air-coupled transducers.

Figure 14: C-scan image of a 15 x 30 cm. section of a SiC panel scanned with 50 kHz air-coupled transducers.

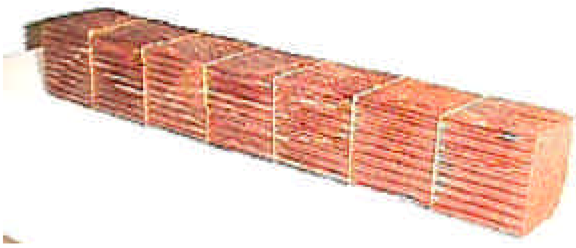
Figure 15: Arithmetic difference between the above two scans

Note the similarities and the discrepancies (highlighted in Figure 15) between the above C-scans. The dark blue areas, which both scans have in common (transmission not frequency dependent), are interpreted as de-laminations. The red areas in figure 14, which correspond to dark blue spots in figure 13 (transmission frequency dependant) are interpreted as areas of increased porosity.

6. Applications of Low frequency Air Coupled Ultrasonic Inspection.

Multi-layer Honeycomb structures

A seven-layer structure was developed for a military aircraft application. The open cell construction at the ends made any conventional approach impossible. Using the 50 kHz system it was possible to transmit sound through the structure and locate areas of de-bonding around 30mm across.



Ballistic armour (Chest Plate)

The dual layer (Aramid-Ceramic) structure requires good bonding between the layers to perform correctly when impacted.

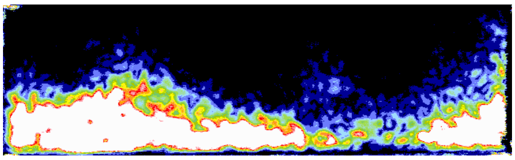
Because of the porous structure of the aramid layer immersion testing is undesirable.

The 50 kHz inspection can find debonded areas around 20 mm across.

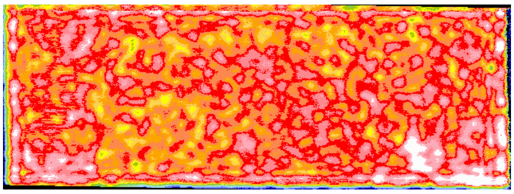
Structural Foam material

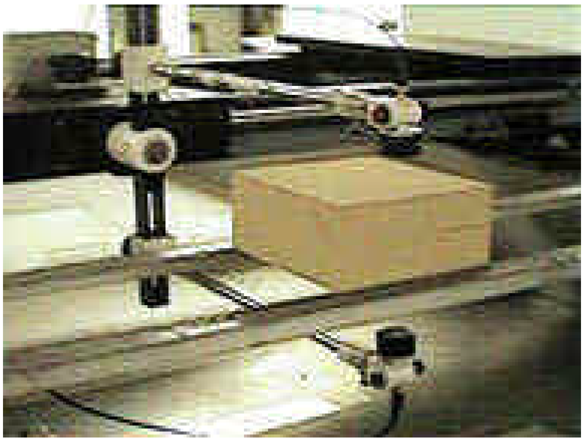
Using the 50 Khz transducers a crack in the material is easily found:

Bad Material:



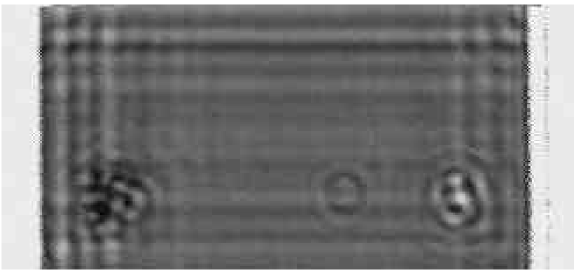
Good material:





Carbon / Foam Sandwich

50 kHz Ultrasound can easily penetrate this experimental material. Unfortunately there was a problem in the manufacturing of this sample, so the defects were not very clear.
The lines are caused by diffraction effects.



7. Conclusions

The ability to achieve moderate resolution at low frequencies, along with extremely good penetration, further extends the range of applications for which Air-coupled Ultrasound can be used. Work is currently underway to further refine its performance. Intermediate frequencies, such as 100 and 200 kHz, also warrant investigation.