Air-coupled Ultrasound for the NDE of Composites

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Introduction

Air-Coupled ultrasound is a very recent development in ultrasonic NDE. The technique has been applied to both homogeneous and composite materials [1]. In the conventional ultrasound, a coupling medium is required to propagate waves from the transducer into a structure. The reason is that the sound at typical ultrasonic NDE frequencies (0.5-50 MHz) does not propagate in air. On the other hand the air-coupled transducers operate in the range of 100-250 kHz and these waves propagate through air.

The main advantage of the air-coupled ultrasound is that the testing can be performed with no contamination of the surface. It can also be implemented in production environment and will not impede the production cycle. So down time for the online inspection can be reduced or eliminated.

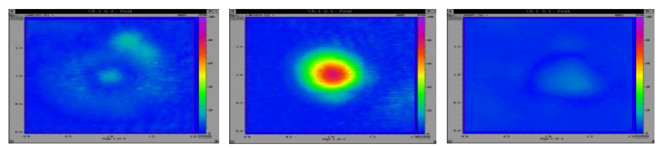
On the other hand air-coupled ultrasound brings its own set of limitations. The frequency is low and so the wavelength is large and hence thin parts cannot be tested. Since the frequency is low, the sound can set up resonance patterns in the part and mask the NDE signal. Hence the wave propagation and resonance have to be properly understood to use the air-coupled ultrasound.

Results and Discussion

The resonance of the part has to be understood properly to understand the resulting pattern observed by the use of air-coupled ultrasound.

We use Finite Element Models to obtain the resonance patterns. This helps us in two ways, first we know the frequencies where the maximum signals pass through the parts and second we know the resonant patterns which can hide the NDE signals.

Inserts are used in Composite structures to provide the hard points for attachments. The insets are typically circular discs. During an investigation of an NDE of the 2.5cm diameter disc was visible at 120 kHz while the 3.8 cm and 1.9 cm discs were not. This problem was solved by FE analysis which showed that the 2.5 cm dia disc had a peak resonance in the axial direction at 120 kHz and hence the large signal transmission.



3.8 cm dia   2.5 cm dia   1.9 cm dia

Fig. 1 NDE of disc of different diameter at 120 kHz

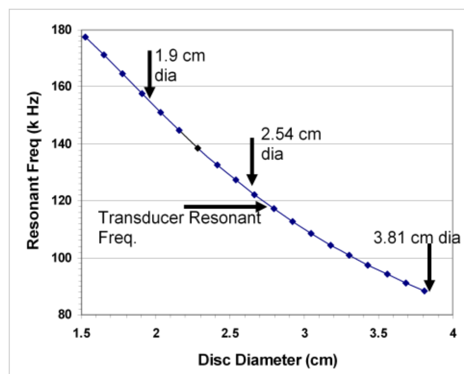


Fig. 2 Resonant longitudinal frequency for cylinders with a thickness of 1.27 cm

Harmonic response of a impact damaged composite plate using Finite Element analysis is shown in Fig.3, which shows the peak resonant frequencies at 120 kHz and 330 kHz. When the same plate was tested by the air-coupled ultrasound [2] it shows the response as shown in Fig. 4. The same damage could not be discerned at 200 kHz.

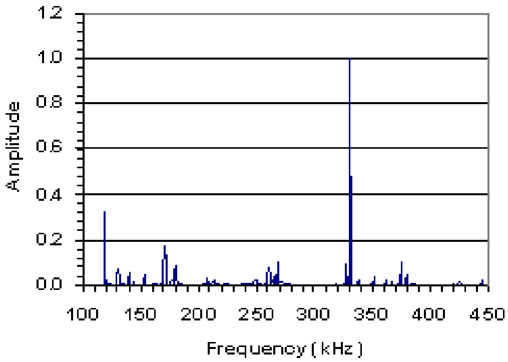


Fig. 3 Harmonic response of an impact damaged composite plate.

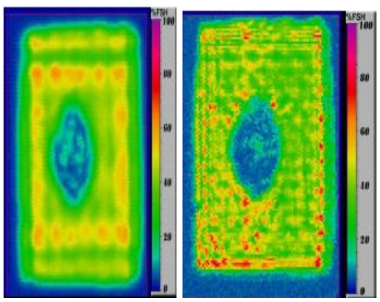


Fig. 4 C-scan of an impact damaged plate at 120 kHz and 400 kHz.

The reflection coefficient of a plate in air is normally very large and hence the amount of energy transmitted into the plate is very small. This problem was investigated and we tried to improve the energy propagation in the plate by the use of Lamb waves [3]. Theoretical model of the plate was developed and the Lamb wave angle of incidence was calculated. Figure 5 shows that if the transmitter and receiver are aligned normally then the signal is smaller as compared to the signal obtained when the composite plate is tilted by a very small angle of 10 deg.

A plate with local resin rich area was investigated and Fig. 6 shows the normal incidence and the oblique incidence scans. It is obvious that the extra energy pumped into the plate in the form of Lamb wave has enhanced the damage.

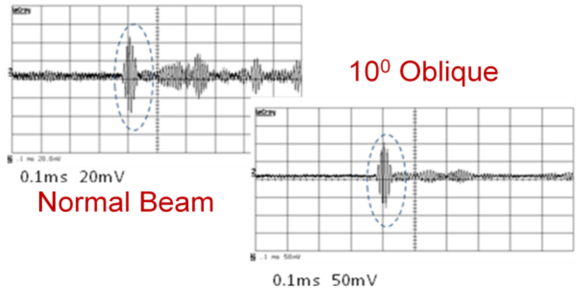
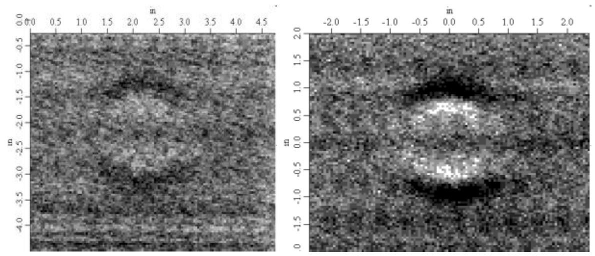


Fig. 5 Air-coupled signal from a composite plate under normal and oblique angles.



Conclusions:

Air-coupled ultrasound is a very convenient and clean NDE tool. But due to the limitation of plate resonance, it has to be properly understood and used. Excellent results can be obtained for the NDE of composite materials.

References:

1. D. K. Hsu, J. J. Peters, D. J. Barnard, V. Kommareddy, and V. Dayal, Experience with air-coupled ultrasonic inspection of aerospace composites, Review of Progress in QNDE, Ed. D.O. Thompson, and D.E. Chimenti (AIP,2003).
2. V. Dayal, D.K. Hsu, and Adam H. Kite, “Air-Coupled Ultrasound-A New Paradigm in NDE”, Proc. Of the Mechanical Engineering Congress and Exposition, Nov.11-15, 2007, Seattle, WA.
3. Plate Wave Resonance with Air-Coupled Ultrasonics, H.N. Bar, V. Dayal, D. Barnard and D.K. Hsu, Review of Progress in QNDE, Ed. D.O. Thompson, and D.E. Chimenti (2009).