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Ultrasonic Testing of Composites – from Laboratory Research to Field Inspections

W. Hillger
DLR Braunschweig, Germany
E-mail: Wolfgang.Hillger@DLR.de

Abstract

*Composites are attractive materials for lightweight structures. In order to inspect these components with ultrasonic imaging techniques optimizations of pulse parameters have been carried out. The know how of the laboratory inspections was successfully employed to field inspections of a specially prepared tail unit of the EH 101. The loss of time for manual scanning is relatively high so that the MUSE-system (**M**obile **U**ltra**S**onic **E**quipment) based on PC-boards with a motor-driven manipulator for automatic scanning was developed. The water circulation system provides local immersion technique. The non-contact ultrasonic technique with air coupling was investigated using a new system called AirTech 4000. This system is based on PC-boards. The AirTech 4000 delivers for sandwich components much higher resolution then inspections with water coupling. Using a Lamb waves a testing from one side is possible.*

1. Introduction

Composites are high-performance materials for lightweight structures especially for lightweight constructions in aerospace, naval and automotive engineering. Their application to primary aircraft structures requires the knowledge of damage incurred after fabrication or in service. Typical damages to be detected are: cracks, delaminations and debondings between skin and stringer, of which only a small part is visible from the outside. The ultrasonic technique is principally able to indicate internal defects.

Composites are non-homogeneous and non-isotropic materials with an extremely high sound damping. Through-transmission techniques with separate receiver and transmitter transducers on opposite sides of the component, is often used for their testing. This method is much easier than the echo technique because the sound has to travel only once in the thickness direction. However, through transmission technique is not practicable for field inspections because of the access is limited to one side of the components.

Special developments for the ultrasonic echo technique were necessary in order to obtain a high degree of evidence. Using immersion technique high frequency and focused transducers deliver excellent resolutions if the pulse parameters are well optimised for the different thicknesses and kinds of materials [1].

2. Mobile Ultrasonic Inspection System „MUSE“

A specially prepared tail-unit of the EH 101 helicopter with impact damages and inserted teflon foils loaded in fatigue equal to 10,000 flight hours was inspected at AGUSTA S.p.A. in Italy. The inspections were carried out in echo technique with a manual scanning system and

imaging in B- and C- scans. The investigation shows that the laboratory research (development of the echo technique for sandwich components) can transmit to field inspections [2]. But the manual scanning was very time-consuming. Reasons were the incorrect coupling in small areas so that those parts had to be inspect again and the large number of points in the C- scans to which the transducer had to be manually positioned [3].
From these experiences the mobile ultrasonic inspection system „MUSE" (**M**obile **U**ltra**S**onic **E**quipment) was developed. This system shown in Fig. 1 consists of a motor-driven manipulation system, a water circulation system for the coupling and the PC-board based ultrasonic system USPC built into a portable computer [4].
The manipulator is attached to the component with sucking devices and accommodates an inspection area of 170mm to 210 mm, a resolution of 0.020 mm and a maximum speed of 100 mm/s. The test frequency range for the MUSE is 0,05 to 35 MHz. Ultrasonic imaging is possible in A-, B-, C- and D- scans.
The coupling technique developed for the MUSE (local immersion technique) provides the application of focused transducers without problems with air bubbles so that the high resolution is also available for field inspections. The local immersion technique is also useful for laboratory investigations because no water tanks are required and the components stay dry.

MUSE-Manipulator with adapter for transducer — *Water circulation system* — *Flaw detector with built-in motor controller*

Fig. 1: MUSE-Manipulator with Water circulation system and Flaw-detector

3. Air coupled ultrasonic testing

The air coupled ultrasonic technique avoids the disadvantages of the coupling liquid or coupling paste like time consuming cleaning after the inspection. Therefore, the non-contact ultrasonic technique is very attractive and very interesting for field inspections.

Fig. 2 shows the amplitude differences between water and air coupling using through-transmission technique with different transmitter and receiver transducers on opposite sides of a thin CFRP specimen. We set the amplitude on the transmitter to 0 dB. Using water coupling, the sound pressure decreases to -21 dB in the water because of the differences in the acoustic impedance of Piezoelectric material (z_{Piezo} =35 MRayl) and water (z_{water} =1.5 MRayl). The amplitude on the CFRP surface (z_{CFRP} =4.5 MRayl) increases to -18 dB and decreases again to -24 dB in the water. At least the amplitude on the receiver becomes -18 dB. This small amplitude difference between transducer and receiver can easily compensated by amplification.

In the case of air coupling, the amplitude difference between transmitter and receiver reaches -156 dB! The extreme high differences between the impedance of air (z_{air} = 0.0004 MRayl) and of the piezo material cause a decrease of -93 dB and also the interface between CFRP and air (-75 dB). In this very simple model only the transmission factors are calculated an no losses of sound attenuation and sound divergences have been regarded.

Therefore, standard flaw detectors and standard transducers cannot be used for air coupling. Special transducers, transmitter- and receiver electronics are required. Since 15 years more and more papers describe the air coupled technique [5]. Normally the investigations are carried out in through transmission technique.

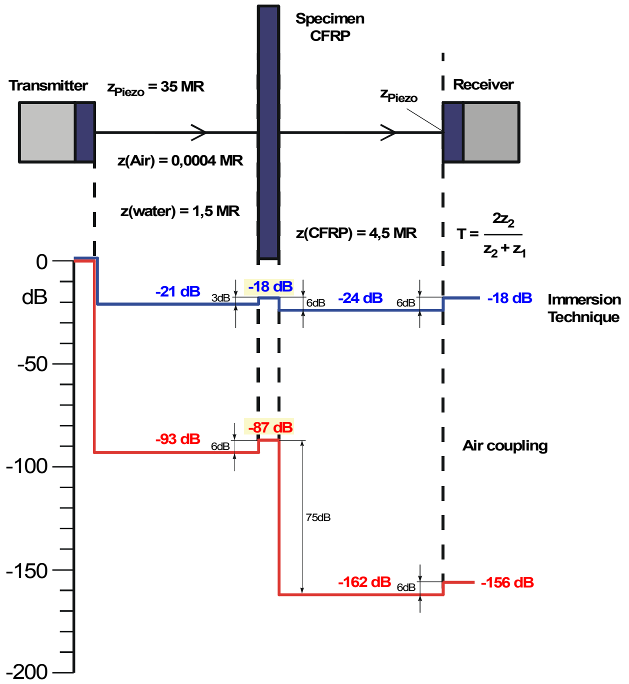


Fig. 2:
Sound pressure curves between transmitter and receiver probe using water and air coupling

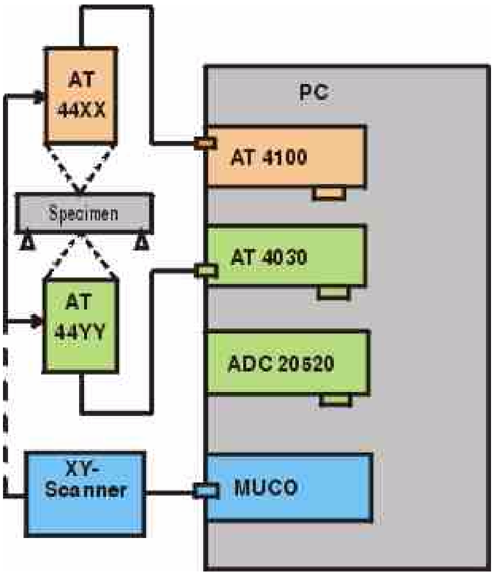


Fig. 3:
Block diagram of the AirTech 4000 built on PC-Boards

4. Ultrasonic system *AirTech 4000*

Fig. 3 shows the block diagram of the ***AirTech 4000***, an ultrasonic imaging system built on PC-boards for non-contact techniques. The system provides a single-shot-evaluation of the echoes. Two transducer pairs with frequencies of 250 and 450 kHz have been developed by IZfP in Saarbrücken (Germany) [6]. The Piezoelectric composite material for the transducers reduce the impedance to 10 to 15 MRayl. The transducers are focused with a beam diameter less than 5 mm in a distance of 45 mm in air.
The length of the transducers is 50 mm, the connectors are Lemo 00, so that they can easily be mounted on scanning systems.
Into the case of the transmitter transducer an electrical impedance matching network was built which increases the amplitude up to 15 dB. The burst transmitter (AT 4100) built on a PC-board generates quartz controlled signals up to 10 cycles with a power of up to 1.2 kW.

A low noise pre-amplifier with matching network and filter unit both consisting of SMD-devices have been additionally built into the case of the receiver transducer. The gain can be controlled by software from 50 to70 dB. The receiver amplifier and filter unit AT 4030 controls the amplification of the preamplifier. Only a simple RG 175 cable is used to receiver which does not only transmits the echo signal, but also the power supply and the gain setting to the preamplifier.

The third board of the AirTech-system is the digitiser (A/D-converter). The module MUCO is the motor controller for the scanning systems. The software provides ultrasonic imaging in A-, C- and D-scans.

5. Comparison between water- and air-coupling

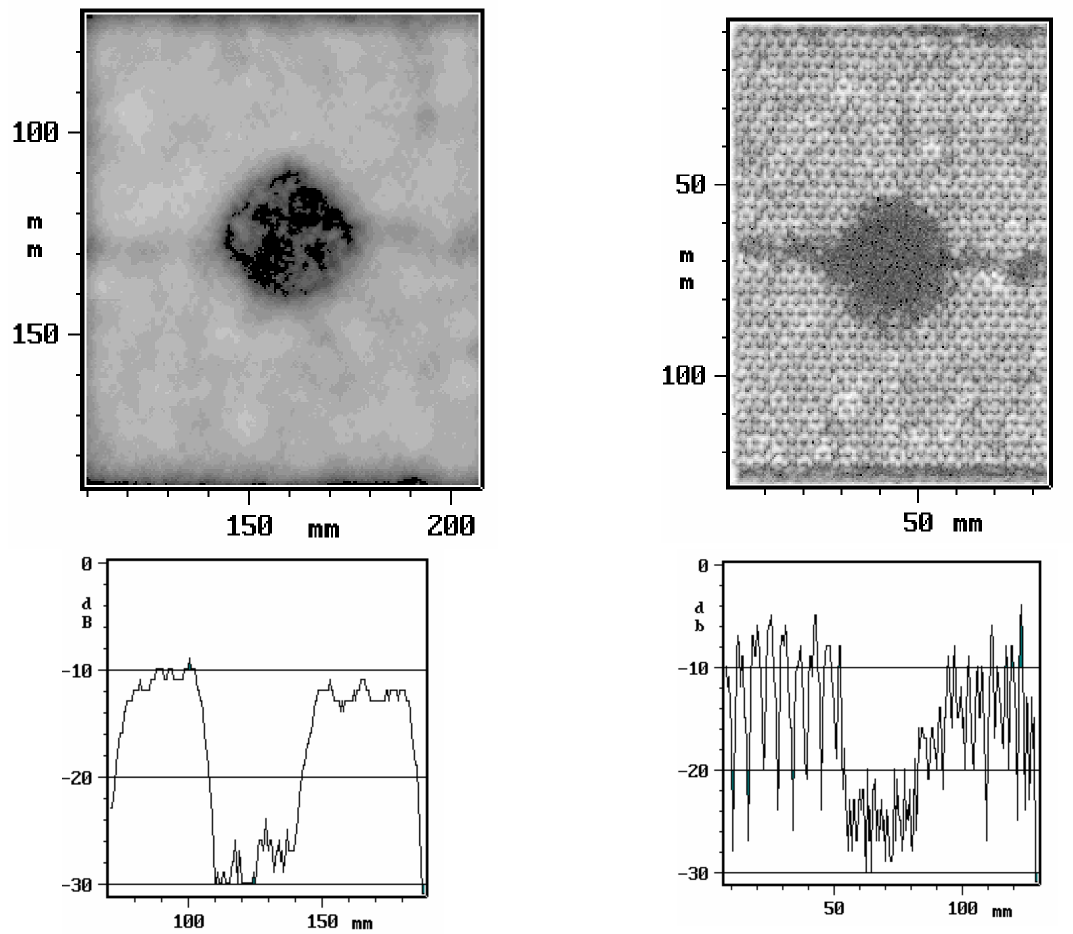
Sandwich components with CFRP skins and Nomex cores - in this case with a total thickness of 14 mm - cause a very high sound attenuation so that the test frequencies have to be in a frequency range from 0.4 to 0.8 MHz [7] (with water coupling). Normally those components are tested in through-transmission technique (squirter technique).
Fig. 4 displays two C- scans of the same sandwich component, on the left hand side with water coupling, on the right hand side with air-coupling. In both cases the 10 J impact is clearly indicated. The air-coupled C-scan demonstrates the high resolution of the ***AirTech 4000*** and gives more details such as the indication of cores. The wave length in water is about five times larger than in air, so that (using the same test frequency) the sound can be focused in air much better than in water and also the resolution of materials with high sound attenuation is much better with air coupling. This result is also impressively indicated by echo dynamic curves below the C- scans in Fig. 4.

6. One-side-testing with air coupling

For field inspections, however, the component can be only tested from one side, so that the through-transmission-technique is not practicable. The application of the echo-technique is not possible because the narrow band transducers generate pulses which are not able to separate the echoes of the interface and the backwall. The generation and detection of Lamb waves in component with a constant thickness opens the possibility for a single-sided inspection [8].
Fig. 5 shows the two 450 kHz transducers (AT 4410 and AT 4420) in one side inspection of a 4,2 mm thick CFRP laminate with an impact damage. The C- scan with Lamb waves clearly indicates the defect. The echo-dynamic curve shows a -16 dB amplitude drop in the defect area. The amplitude of the Lamb waves is very sensitive to the alignment of the transducers. In spite of this it is possible to have a non-contact one-side-inspection of CFRP-components.

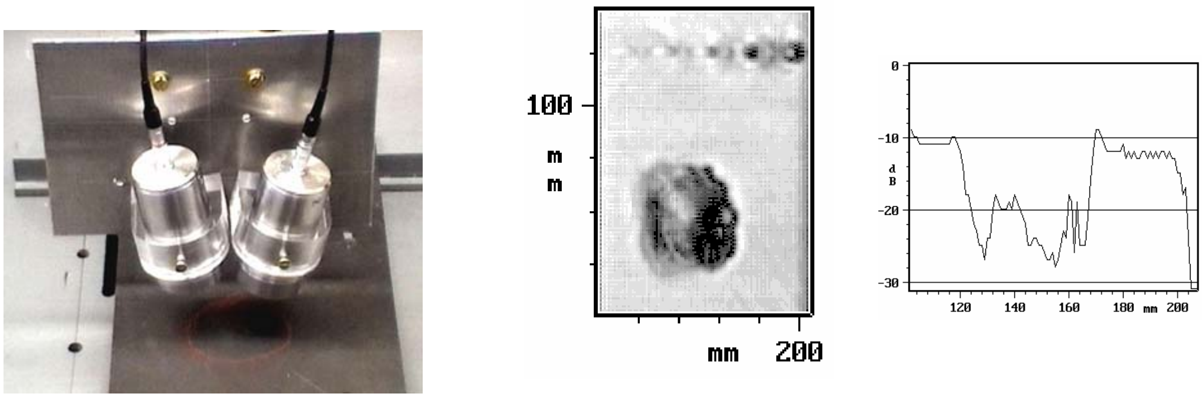
6. Summary

CFRP components are attractive materials for space and aircraft applications. The high inhomogeneity and anisotropy of these materials case an extremely high sound attenuation. The ultrasonic imaging technique must be capable of detecting all kinds of defects such as



Water coupling Air Coupling

Fig. 4: Comparison between water and air- coupling using a CFRP-sandwich component with impact damage



Inspection from one side with air coupling C- Scan and echo dynamic curve

Fig. 5: Testing a 4.4 mm thick CFRP-laminate with an impact damage from one side with air coupling with C-scan and echo dynamic curve

delaminations, debondings. The inspections cannot not be limited to laboratory use, but also be practicable for field-inspections of „real“ structures.

Therefore the MUSE- system (**M**obile **U**ltra**S**onic **E**quipment) with a motor-driven manipulator and a special water circulation system for coupling has been developed. The MUSE provides ultrasonic imaging of internal defects.
In order to have a non-contact inspection investigations with air coupling were carried out with the new AirTech 4000 system. This system is built on PC-boards and provides ultrasonic imaging in single shot technique. In spite of the large differences between the acoustic impedances of air and solids the resolution with air coupling is much better than those with water. The echo technique is not possible because of the large pulse length of the narrow band transducers. The application of Lamb waves opens the possibility of a one side testing which is very necessary for field inspections. It was shown that the method can indicate delaminations in CFRP laminates with constant thickness. The Lamb wave amplitude is very sensitive to the alignment of the transducers. A project for the further development of the transducers and of the electronics has been started for the application of the echo technique.

7. References

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