Practical Applications of Air-Coupled Ultrasonic Technique

Wolfgang HILLGER, Detlef ILSE, Lutz BÜHLING
Ingenieurbüro Dr. Hillger, Wilhelm-Raabe-Weg 13, 38110 Braunschweig, Germany,
www.dr-hillger.de, info@dr-hillger.de

Abstract. Since more than 20 years the air-coupled ultrasonic technique already exists. Problems caused by the large acoustic mismatch between solids and air are solved with special transducers, a powerful excitation as well as a hard- software signal processing. The USPC 4000 AirTech includes a powerful burst-pulser, an ultra-low pre-amplifier and a band pass filter amplifier. The combination of hard- and software filters increases the signal-to-noise ratio up to 50 dB. The software imaging Hillgus for Windows enables an easy control of the system and of the different manipulators as well as evaluation and measuring functions of the C-scans.

Air-coupled ultrasonic testing requires separate transducers as a sender and receiver on opposite sides of the component. Pitch and catch technique require only a single sided access. Because of critical adjustments this method is preferable only for laboratory applications. However, a robust inspection requires a two sided access. This paper presents details of automated scanning systems for tube-shaped- and flat CFRP- and CFRP honeycomb components.

Introduction

Ultrasonic testing is the most used Non-destructive method for components. During the last 30 years the progress of the computer technique has enhanced the possibilities of ultrasonic imaging. However usually ultrasonic inspections require an acoustic coupling media. For ultrasonic imaging of composites water is an ideal media because the acoustical impedances are in the same dimension which enables an excellent sound penetration of the component. It is not easy to provide a constant coupling of large components because of air bubbles and lime scales. Water also causes corrosion of the scanning mechanics. The squirter technique demands a constant water pressure and a precise adjustment. A lot of inspections are not possible with coupling liquids (water) or coupling paste because of incoming water. Using air-coupled techniques no coupling liquid like water is necessary. These advantages are dearly paid by an acoustical mismatch between solids (transducers, test component) and air (coupling) [1-3]. The acoustical mismatch of the transducers can be reduced by a matching layer (from 80 to 90 dB down to 40 dB amplitude loss). The acoustical mismatch caused by the test component (70-80 dB) cannot be reduced. Therefore a special equipment is necessary. Non-contact techniques have mostly been used for laboratory applications because the echo technique can not be applied. Since more than 12 years the company Ingenieurbüro Dr. Hillger has been developed systems for this special coupling technique for laboratory as well as industrial applications [4].
1 Ultrasonic Imaging System USPC 4000 AirTech

1.1 Overview

The system consists of transducers, transmitter for a powerful pulse excitation, an ultra-low preamplifier, a receiver amplifier and a digital to analogue converter. On the other hand a mechanical scanning system adapted to the design of the component and -of course software for the system control, data acquisition and imaging are required. A block diagram of the complete system USPC 4000AirTech is shown in Fig. 1.

Fig. 1. Block diagram of the Air-coupled ultrasonic system USPC 4000 AirTech

1.2 Transducers

It is not possible to use standard transducers for air-coupled ultrasonic technique because of the large acoustical mismatch between the transducer and the surrounding air. Immersion transducers would produce decrees of up to -90 dB in amplitude.

Because of their low acoustic impedance the application of special ferroelectric foils is under investigation. In opposite to piezoelectric material ferroelectric foils do not need matching layers [5]. Their high electrical impedance exacts a high transmitter voltage (2.5 kV). These transducers are currently in development.

Piezoelectric materials are very robust. For an air-coupled application a matching layer is required. Best output delivers a thickness of a quarter of a wavelength. The Ingenieurbüro Dr. Hillger has developed transducers in frequency range from 50 to 300 kHz (Fig. 2, Tab. 1). These relative low frequencies compared with standard ultrasonic testing are necessary because of the frequency dependant attenuation in air. Besides the frequency the most important parameter of transducers for air-coupling is their sensitivity $S$ given by:

$$S = 20 \log \left( \frac{V_R}{V_T} \right), \quad V_T = \text{excitation in volts}, \quad V_R = \text{receiver signal amplitude in volts}, \quad (1)$$

which is measured in through-transmission-technique with air-coupling and without a specimen. For the AirTech 120 transducers a tone-burst signal excitation with a voltage of
190Vss, the receiver transducer generates a voltage of 4.2 V! Equation (1) delivers in this case -33 dB, which is a value of the best air-coupled transducers.

Tab. 1 resumes all important data. The transducer provides a relative bandwidth of ~10 %.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>AirTech50</th>
<th>AirTech75</th>
<th>AirTech120</th>
<th>AirTech200</th>
<th>AirTech300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth [kHz]</td>
<td>50</td>
<td>75</td>
<td>125</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Active element Ø [mm]</td>
<td>44.5</td>
<td>30</td>
<td>19</td>
<td>11</td>
<td>7.1</td>
</tr>
<tr>
<td>Max. voltage [Vpp]</td>
<td>1500</td>
<td>1000</td>
<td>800</td>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>Near field length [mm]</td>
<td>73</td>
<td>50</td>
<td>32</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Sensitivity [dB]</td>
<td>-33</td>
<td>-31</td>
<td>-32</td>
<td>-33</td>
<td>-52</td>
</tr>
</tbody>
</table>

Table 1. Technical data of AirTech Transducers

1.3 Ultrasonic System

The USPC 4000 AirTech shown in Fig. 1 consists of a scanner (see chapter 2) with controller, the two transducers with fixtures (one as a transmitter, the other one as a receiver), an ultra-low noise preamplifier, a pulser unit and the components built in an industrial PC with Windows™ operating system. The main amplifier and the programmable pulser unit are situated on PC-boards.

The programmable pulser provides a power of up to 1.2 kW. This board does not only produce quartz-controlled tone-burst pulses (from n = 1 to 15 in the frequency range from 20 kHz to 1 MHz), but also free programmable pulses generated by a digital arbitrary generator. Therefore, chirp and coded signals can be used in order to increase the signal to noise ratio.

The receiver of the USPC 4000 AirTech consists of an ultra low noise preamplifier (matched to the receiver transducer), a main amplifier with digital gain control and frequency filters and a 14 bit analogue to digital converter board (ADC). The separate preamplifier provides a short cable to the receiver transducer which prevents the reception of electromagnetic noise and additional signal attenuation by the capacity of a long cable. A cable length up to 30 m from the preamplifier to the UCPC 4000 AirTech system is uncritical because of the 50 Ohms technology. The gain setting of the preamplifier is software controlled (6 to 46 dB).

The UCPC 4000 AirTech is assembled in 19-inch housing together with the computer. Fig. 5 (right hand side) presents the hardware in a 19” inch rack together with a scanner controller.
Fig. 3 gives an impression of the easy to handle software Hillgus for Windows which provides scanner and ultrasonic parameter settings, data recording (including full wave), real-time A-scan display, B-, C- (amplitude) and D- (time of flight) scans. The software enables calculations of A-, B, C- and D- scans with different parameters out of full-wave data. The Oculus software provides evaluation of all scans including automatic measurements of defects.

2. Scanning Systems

2.1 Requirements

For data recording a scanning system has to move the transducers in meander shaped way. For laboratory testing a one sided access with pitch and catch can be carried out [6]. The required high precision alignment of the transducers can not be achieved for large and complex curved components. Usually the testing is carried out in through-transmission technique with separate receiver and transmitter transducers on opposite sides of the component. The scanning system has to be optimized for the design of the component.

2.1 FlatScan

The FlatScan system is a robust scanner for the inspection of flat components up to a thickness of 90 mm in through-transmission technique as well as pitch and catch. This system shown in Fig. 4 consists of two synchronously moving scanning axes on opposite sides of the component and one axis in x-direction. The mechanical resolution is 0.15 mm, the maximum scanning speed is 500 mm/s. There several scanning systems with different scanning areas up to 1500 to 1000 mm are available. The fixtures for the transducers enable an easy adjustment of the distances between of the transducers and the surface of the test component.
2.2 Inspection system for rotationally symmetrical components

Fig. 5 presents the scanning system for rotationally symmetrical composite components in through-transmission technique. This system consists of two CFRP beams with integrated transducers and preamplifier. The beams are moved by a stepper motor into the component (scanning axis). The component is rotated by roller carriage. The maximal length of the component is 2100 mm, the diameter range between 200 and 1600 mm.

2.3 Robot manipulation

For the inspection of complex shaped components a multi-axial scanning system is required. The company Rob-Technology already has great experiences in the programming of robots systems, including the coupling of two robots on opposite sides [7]. Using a robot instead of an xy-scanner for the ultrasonic system USPC 4000 AirTech a high precision three dimensional and temporal synchronisation between all axes and the ultrasonic system had to be developed. Fig. 6 shows a robot demonstrator with a bracket fixture with two
AirTech transducers. This demonstrator has been the basic for the Eurocopter air-coupled ultrasonic system in Donauwörth/ Germany for the tailboom of the helicopter EC 145 T2 described in [8-9].

Fig. 6: A robot used as an xy-scanning system (demonstrator)

3. Results

In comparison to water-coupling the application of air-coupled technique enables a high resolution especially for composite components with high sound attenuation. These materials like foam or honeycomb sandwich components require low test frequencies. The clear indication of defects caused by impacts in a sandwich component with metallic honeycomb cores (for space applications) can be seen in the C-scan of Fig. 7. The inspection is carried out with AirTech 120 transducers. In spite of this low frequency the amplitude decrease caused by a defect is more than 20 dB. This result is presented by the echo dynamic curve in Fig. 8.

Even form core components can easily be inspected. Because of the high sound attenuation the test frequency have to reduce down to 75 kHz (AirTech 75).

Fig. 7: C-scan of a sandwich component

Fig. 8: Echo dynamic curve along x=175 mm in Fig. 7
Conclusions

Air-coupled ultrasonic imaging prevents all disadvantages of coupling water like corrosion and air-bubbles in the coupling path. In spite of the large acoustical mismatch inspections of composites deliver excellent results thanks to optimized ultrasonic equipments like USPSC 4000 AirTech. For industrial applications the robust transmission technique with separate receiver and transmitter transducers on opposite side of the component provides a good solution. In dependence of the application the scanning systems require up to 10 axes. For complex components two synchronized robots can be used.

References


