New Developments for Air-coupled Ultrasonic Techniques

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Abstract. After 15 years of more or less laboratory applications the air-coupled ultrasonic technique (ACU) is used for large aerospace construction parts like the EC 145 tail boom and payload fairings. This kind of set-ups use ACU in through-transmission technique with sender- and receiver-transducers on opposite sides of the component. Because of the complex curved components robot scanners with 10 axes are necessary for the manipulation and the alignment of the transducers. The large component sizes require travelling lengths of 20 meters and more.

The new developments are focussed to

- eight channel systems with sender and receiver arrays, reduces the time for scanning to 1/8 of the time for a one channel system

- ACU with one sided access, which will reduce the number of axes to ½ of a through transmission system

- an ultra low noise amplifier (ULNA) which reduces the RMS-value of noise by 4 dB.

- new transducers based on polarized cellular polypropylene (cPP) materials

This paper reports about these developments and about first results.

Introduction

Usually, ultrasonic inspections require an acoustic coupling media between the transducer and the test component. For example water is an ideal coupling medium for composites because of the acoustical impedances are in the same dimension which enables an excellent sound penetration of the component. However, on the other hand 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 water jet technique requires a constant water pressure and a precise adjustment in the case of through-transmission technique. A
lot of inspections are not possible with coupling liquids (water) because of incoming water. Using air-coupled ultrasonic techniques (ACU) 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, 2]. 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 special equipment is necessary. ACU have mostly been used for laboratory applications because the echo technique cannot be applied. First papers of ACU are published in the 70th [3, 4]. For more than 15 years the company Dr. Hillger Ultrasonic techniques is developing systems for this special coupling technique for laboratory as well as industrial applications [5-7]. Because of the frequency attenuation in air increases exponentially with the frequency ACU is carried out in the frequency range below 1 MHz.

1. System and its application for aerospace components

1.1 Ultrasonic system

The imaging system USPC 4000 AirTech consists of transducers, transmitter for a powerful pulse excitation, an ultra-low noise preamplifier, a receiver amplifier and a digital to analogue converter, an industrial computer for setting and evaluation. On the other hand a mechanical scanning system adapted to the design of the component and a Hillgus software for the system control, data acquisition and imaging are required. The complete system USPC 4000 AirTech with FlatScan [6] is shown in Figure 1.

![USPC 4000 AirTech with FlatScan](image)

**Fig. 1.** USPC 4000 AirTech with FlatScan.

1.2 Transducers

Immersion transducers used for ACU would produce decreases of up to -90 dB in amplitude because of the large acoustical mismatch between the transducer and the surrounding air. Therefore it is necessary to use special transducers for air-coupled
ultrasonic technique. Piezoelectric transducers are mostly used for ultrasonic testing and are distinguished by a high degree of effectiveness between electric and acoustic energy. The high acoustic impedance of the piezo requires a $\lambda/4$ matching layer which forms a narrowband frequency filter so that long ultrasonic pulses are generated. In order to obtain high amplitudes a damping unit is not used. For robust industrial applications we have developed piezoelectric transducers with one matching layer in frequency range from 50 to 300 kHz (Figure 2). These relative low frequencies compared with standard ultrasonic testing are necessary because of the frequency dependent attenuation in air. Using a tone-burst signal excitation with a voltage of 190V$_{ss}$ for the AirTech 120 transducer the receiver transducer generates a voltage of 4.2 V! This means a sensitivity of -33 dB, which is a value of the best air-coupled transducers. The transducer provides a relative bandwidth of $\sim 10\%$. see Table 1.

### Table 1. Transducers

<table>
<thead>
<tr>
<th>Transducer</th>
<th>Frequency</th>
<th>Active-ø</th>
<th>Near field length</th>
<th>Beam-ø</th>
<th>Wavelength in air</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AirTech 50</td>
<td>50 kHz</td>
<td>44.5 mm</td>
<td>73 mm</td>
<td>13 mm</td>
<td>6.8 mm</td>
<td>-33dB</td>
</tr>
<tr>
<td>AirTech 75</td>
<td>75 kHz</td>
<td>30.0 mm</td>
<td>50 mm</td>
<td>8 mm</td>
<td>4.5 mm</td>
<td>-31dB</td>
</tr>
<tr>
<td>AirTech 120</td>
<td>125 kHz</td>
<td>19.0 mm</td>
<td>32 mm</td>
<td>5 mm</td>
<td>2.8 mm</td>
<td>-32dB</td>
</tr>
<tr>
<td>AirTech 200</td>
<td>200 kHz</td>
<td>11.1 mm</td>
<td>18 mm</td>
<td>3 mm</td>
<td>1.7 mm</td>
<td>-33dB</td>
</tr>
<tr>
<td>AirTech 300</td>
<td>300 kHz</td>
<td>7.1 mm</td>
<td>12 mm</td>
<td>2 mm</td>
<td>1.1 mm</td>
<td>-52dB</td>
</tr>
</tbody>
</table>

### 1.3 Scanners

The FlatScan system is a robust scanner for laboratory and industrial applications for the inspection of flat components with a mass lower than 50 kg and up to a thickness of 90 mm in through-transmission technique as well as pitch and catch. This system shown in Fig. 1 consists of two synchronously moving scanning axes on opposite sides of the component and one axis in x-direction. The mechanical resolution of all axes is 0.15 mm; the maximum scanning speed is 200 mm/s. Systems with scanning areas up to 3000 x 2000 mm are available.

For the testing of rotationally symmetrical composite components in through-transmission technique the RobockScan scanning system has been developed [8]. This system consists of two CFRP beams with integrated transducers. 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 up to 7000 mm, the diameter range between 200 and 1600 mm. The mass of component can reach 300kg.

### 1.4 Robot systems

For the inspection of complex shaped components a multi-axial scanning system is required. The company Robo-Technology already has great experiences in the programming of robots systems including the coupling of two robots on opposite sides. 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. The synchronisation has been tested with a demonstrator which has been the basic for the Eurocopter air-coupled ultrasonic system in Donauwörth/ Germany for the tail boom of the helicopter EC 145 T2 [9].
One of the largest air-coupled systems in the world is called ANDI has been installed in Emmen, Switzerland. Two transducers are positioned synchronously and antiparallel along the curved component surface. Fig. 2 shows the system consisting of two robots, one inside the component, the other one outside [10]. The outer scanning system consists of a FEM-optimized cantilever with a special CFFR robot. This system has a half cylinder inspection range with a length of 21.7 m and a width of 5.4 m. The maximum velocity is 1m / s. The time for the inspection is dependent on the scanning grid and takes about 36-72h. The accuracy reaches less than 2.5 mm (for a length of 21m!), the automatic distance control between the component and the probes provides a difference of +/- 1mm. In spite of a gain of more than 70 dB and a transducer cable length of 50 m no noise of the 20 powerful motors of the mechanics can be indicated in the A-scans. A highlight is the go-to function triggered by a mouse click in the C-scan. This function is very useful after scanning the component. The C-scan can be loaded as a reference scan in the manipulator area of the user interface. In the case of a defect indication the user can click into the C-scan, the manipulation system moves to the selected point and the A-scan at this position is indicated.

![Fig. 2. Air-coupled ultrasonic equipment ANDI for space components with 21 m scanning length.](image)

3. Special developments

3.1 Multichannel systems

In order to decrease the time for scanning we have developed fast eight-channel parallel technique which combines electronic and mechanic scanning. The system consists of a transmitter array AirTech 200-8T, a receiver array AirTech 200-8R and the AirTech 4008 system built in an industrial 19”-case. The arrays provide a test frequency of 200 kHz. The receiver array does not only contain the eight ultrasonic elements but also the eight ultralow noise preamplifiers and the analog signal processing. A cable length to the AirTech system of more than 50 meters causes no difficulties. The software Hillgus had to be expanded for scanning with arrays and for 8 channel parallel data recording. This includes the array definition. The resolution of the multichannel ADC provides a high resolution of 16 bits with a high dynamic range of the amplitude measurement. A scanning grid down to 0.15 mm is possible. Fig. 3 shows the two arrays arranged in pitch and catch technique for a one-sided access. These investigations are part of the BUC-project (see 5.)
The scanning time with a FlatScan scanner (see Figure 1) of a 1x1 m plate is reduced with our new 8 channel system USPC 4008 AirTech from 28 minutes with a one channel system down to 4 minutes (each with a grid of 1.5 to 1.5 mm). Arrays with frequencies of 120 kHz are also deliverable.

3.2 Improved preamplifier

Especially the noise of the preamplifier reduces the signal to noise ratio of the system and can deliver diffuse C-scans. The ambitious aim was to develop a preamplifier with a noise as low as possible. For the output noise not only active elements like operation amplifiers and transistors produce noise, but also each resistor in the circuit. The generated noise is a combination of the voltage- and the current noise. The current noise produces a voltage noise at the internal resistance of the signal source (receiver transducer). Each resistor at the input of the preamplifier generates noise proportion to its resistance. The problem could be solved by a combination of discrete and integrated active components. The result of our research and developments is a new ULN (ultra low noise) preamplifier AirTech 4050 which replaces the AirTech 4028. This new ULN amplifier technique can also be built directly in our transducers. An example is shown in Fig. 4.

Fig. 3. Eight-channels array-technique in pitch and catch.
3.3 New Transducers

Ferroelectrets, especially polarized cellular polypropylene (cPP) materials can be used without matching layers instead of PZTs because of their low acoustic impedance [11]. The transmitted signal shows no ringing and the bandwidth is much larger. However the electrical impedance is very high in comparison with PZT, so that special electrical impedance matching is necessary. In cooperation with the BAM in Berlin, Germany, we will bring this kind of transducers to market.

3.4 Software FFT image

The application of transducers with larger bandwidths (see 3.3) enable the evaluation of frequency shifts in a frequency C-scan. This kind of C-scan displays the maximum frequency in a gate range. Therefore the colour palette is scaled in frequency. Fig. 5 shows the result of a fibre-ceramic test specimen of DLR WF-SFK in Köln, Germany. In this test body the frequencies used occur primarily $\lambda/4$-resonances or their $\lambda$ multiples. Thereby, the amplitude amplified at some points, to the other there occurs a weakening, as in usual defects. Because the cPP- transducer has a higher relative bandwidth than the AirTech probes, the frequency scan delivered additional information (Fig. 5). The frequency profile (Fig. 6) clearly indicates the frequency changes along a scan line. The centre frequency is situated at 280 kHz, the variations are at 300 and at 270 kHz. It has to be examined with CT findings, whether the different $\lambda/4$-resonance with the "flaw depths" correlate. It then states a possibility of determining the failure depth at air-coupled ultrasound.
3.5 ACU with one-sided access

Within the BUC project we investigate the possibility of ACU with a one sided access of the test component using Guided waves. These kinds of waves can penetrate large areas with small attenuation. Their excitation can be carried out with angular incidence of sound or with applicative piezo patches. The defects and other stiffness changes cause interactions with the two wave modes (in minimum). For optimal indications the test parameters have to be optimized carefully. After scanning the component and recording a volume scan with the whole information about the wave propagation and interactions, a special evaluation is necessary in order to receive a C-scan. A first result is shown in Fig. 7, the test result of a monolithic CFRP panel. The defects are clearly displayed. Further investigations will be focused to actuators and evaluation software.

4. Conclusions

Air-coupled ultrasonic imaging prevents all disadvantages of coupling with 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 the optimized ultrasonic equipment like USPC 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. For complex components two synchronized robots with up to 10 axes can be used. Components with a high degree of sound attenuation like sandwich components with honeycomb cores and even with foam core which can penetrate only low frequencies this technique delivers a better resolution than the water jet technique. In spite of all optimizations the application of echo technique is not possible for the detection of internal defects. Therefore complex geometries require a two sided access for the inspections.

New developments are focused to one sided access of the component and higher resolution for the ACU for replacing the water-coupled UT for monolithic components.
Fig. 7. ACU C-scan recorded with one-sided access.

5. Acknowledgement

The new developments are part of the BUC project. BUC is an acronym for non-contact ultrasonic testing. We would like to thank the German Government (BMBF – KMU innovative) for their support.

References


