

INDUSTRIAL APPLICATIONS OF AIR-COUPLED ULTRASONIC TECHNIQUE

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Abstract. Ultrasonic technique is the most used NDT-method. Usually ultrasonic testing of complex aerospace components is carried out with water jet technique. However, water coupling delivers disadvantages like pressure variations and therefore amplitude variations, air-bubbles, lime scales, algae and corrosion of the mechanics. Also incoming water can destroy the components by freezing. Air-coupled ultrasonic technique (ACU) which already exists since more than 20 years avoids these disadvantages. The large acoustic mismatch between solids and air produced by ACU are solved with special transducers, a powerful excitation as well as a hard- software signal processing by our USPC 4000 AirTech system. The software Hillgus4 and Oculus enable an easy control of the system and of the different manipulators, a data recording with on-line C-scan as well as evaluation and measuring functions of the C-scans.

However, in spite of all developments for ACU the echo-technique is not practicable for the indication of internal defects. ACU requires separate transducers as sender and receiver. Pitch and catch technique require only a single sided access. Because of critical adjustments this method is only preferable for laboratory applications. However, a robust inspection of complex-curved components requires a sender transducer and a receiver transducer each perpendicularly orientated to the surface on opposite sides of the component.

This paper presents details of automated scanning systems for tube-shaped- and flat CFRP- and CFRP honeycomb components. Because of the coaxial alignment of the transducers on opposite sides of a complex component a ten axes robot scanning system is necessary. An automated air-coupled robot ultrasonic imaging system is in operation by Airbus Helicopters in Donauwörth/Germany. Larger devices for sandwich space components are installed in Zürich/Switzerland. A 10 axes scanning system has a mass of 18 tons. These projects have been a co-operation between Robo-Technology, Dr. Hillger and Eugen Ostertag.

New developments are focused on ultra-low noise preamplifiers, multi-channel systems and one-sided access of air-coupled ultrasonic. The project is called BUC which means non-contact ultrasonic testing. We would like to thank the German Government (BMBF – KMU innovative) for their support.

Introduction

Usually, ultrasonic inspections require an acoustic coupling media between the transducer and the test component. For example water is an ideal coupling medium because 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]. Because of the frequency attenuation in air increases exponentially with the frequency ACU is carried out in the frequency range below 1 MHz.

1. Ultrasonic System

1.1 USPC 4000 AirTech

The imaging system consists of transducers, transmitter for a powerful pulse excitation, an ultra-low preamplifier, a receiver amplifier and a digital to analogue converter and a computer for setting and evaluation. 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. The complete system USPC 4000 AirTech with FlatScan [6] is shown in Figure 1.

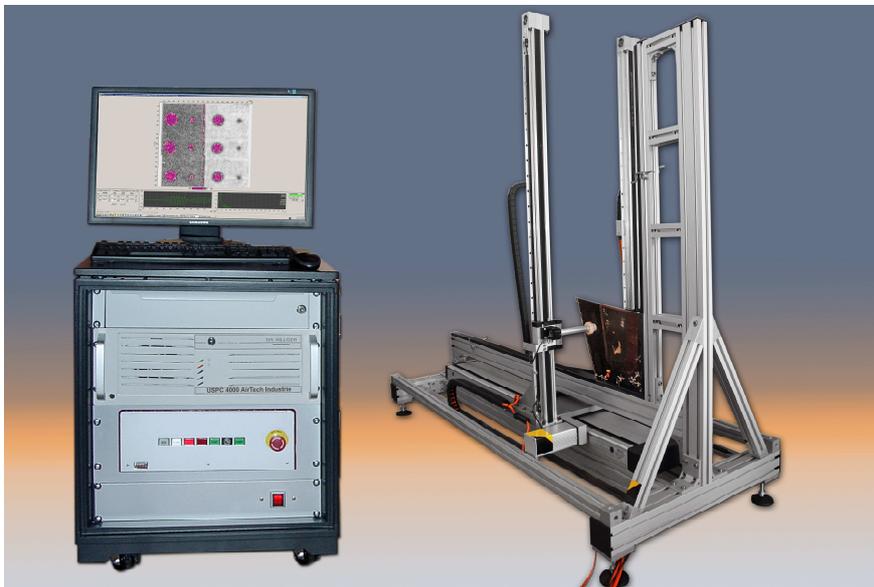


Figure 1. Air-coupled ultrasonic system USPC 4000 AirTech with FlatScan

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.

Piezoelectric transducers are most 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 generates 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 dependant 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 ~10 %.



Figure 2. AirTech transducers with frequencies from 300 down to 50 kHz

1.3 New ultra-low noise amplifier

The noise of the preamplifier reduces the signal to noise ratio of the system and provides diffuse C-scans. The goal 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. A combination of discrete and integrated components provides 3 dB lower noises. The new preamplifier AirTech 4050 is used instead of the AirTech 4028. We will built in the case of the receiver transducer.

1.4 New eight channel System AirTech 4008

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 ultra-low 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 4 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 is 16 bits which provides a high resolution with a high dynamic range of the amplitude measurement. A scanning grid down to 0.15 mm is possible.

The scanning time with a FlatScan scanner (see Figure 1) of a 1x1 m plate is reduced from 28 minutes with a one channel system down to 4 minutes with our new 8 channel system (each with a grid of 1.5 to 1.5 mm).



Figure 3. AirTech transmitter and receiver arrays

2. Special multi-axial systems

Inspection of large complex curved aerospace components is totally different from laboratory investigations of flat specimens [7]. These components require a 10 axes scanning system. The ultrasonic resolution for the special component has to be defined which also defines requirements of the scanner. A too high resolution means a too large cost of a ten axes system.

Using a robot instead of a XY-scanner for the ultrasonic system USPC 4000 AirTech a high-precision three dimensional and temporal synchronisation between all axes and the ultrasonic system is required. In co-operation with the company Robo-Technology GmbH a hard- and software interface for this synchronisation has been developed.

This was the pre-condition for the test facility of the EC 145 helicopter tail-boom in Donauwörth, Germany, which has been designed in co-operation with Airbus-Helicopters, Airbus Group Innovations, Robo-Technology, Ostertag und Dr. Hillger (Figure 4) [8]. This equipment with dimensions of 5.3 m x 4.9 m and a height of 10.6 m fulfils all requirements for the inspection of the honeycomb part of the tail boom [9].

Another air-coupled ultrasonic system with travelling distances of is 5.7 x 4.0 x 2.5 m has been started up in 2014 at the company Ruag Space in Zürich, Switzerland, in co-operation with Robo-Technology and Eugen Ostertag (Figure 5).

One of the largest air-coupled systems in the world is called ANDI just installed in Emmen, Switzerland. Two transducers are positioned synchronously and antiparallel along the curved component surface. Fig. 6 and 7 show 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 CFRP 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 provide a difference of +/- 1mm. The component mounts are adjustable in order to compensate small tolerances of the component and can be separately threaded when this range is tested.

The ultrasonic measurements are made in the fixed grid also in synchronism with the robot motion.

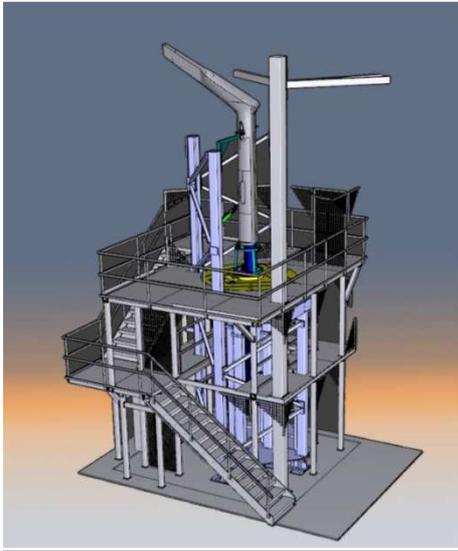


Figure 4. 10-axes-scanning system for non-contact inspection of the EC 145 Tail



Figure 5. 10-axes-scanning system for non-contact inspection of sandwich space-structures

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.

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.



Figure 6. Air-coupled ANDI system with two robots [13]

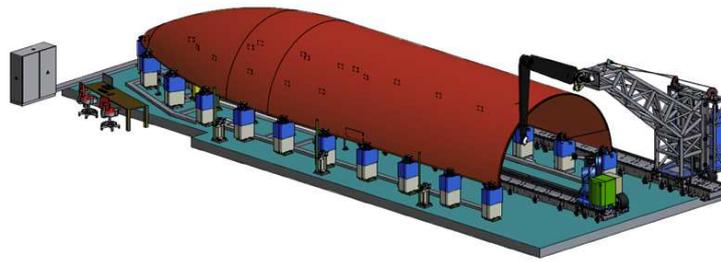


Figure 7. ANDI system with test component

3. ACU with one sided access of the test component

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 intromission of sound or with applicated 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 Figure 8, the test result of a monolithic springer stiffened CFRP panel. The stringers and the repair are clearly displayed. Further investigations will be focused to actuators and evaluation software. These activities are part of the BUC-project.

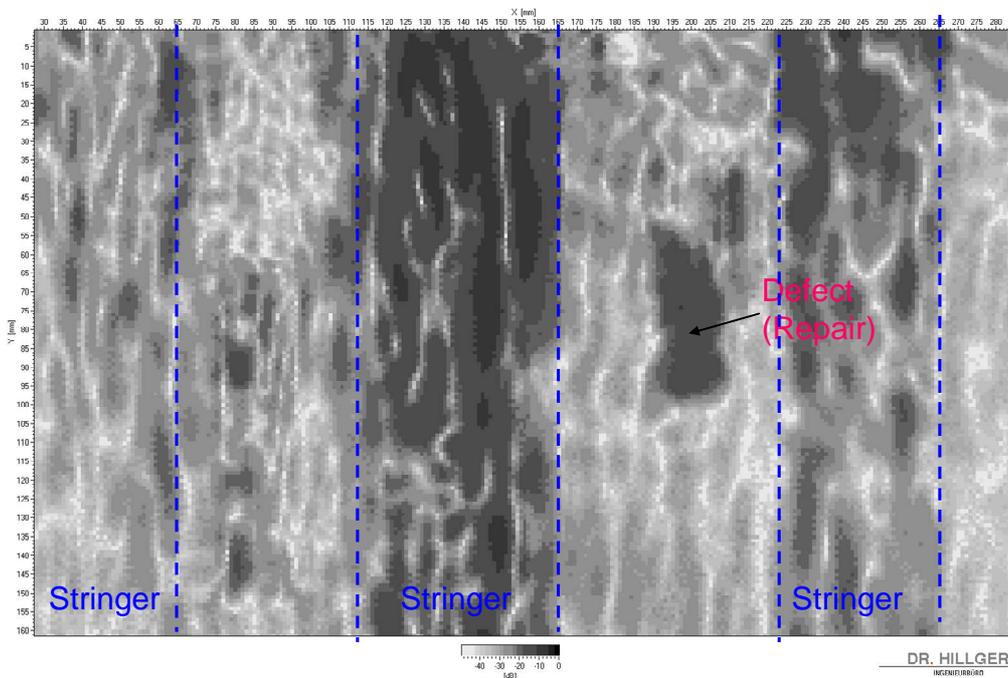


Figure 8. First result of ACU with one sided access

4. 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 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 up to 10 axes. For complex components two synchronized robots 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 a multi-channel system, ultra-low noise amplifiers and one sided access of the component.

5. Acknowledgement

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

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