Automated Air-Coupled Ultrasonic Technique for the Inspection of the EC145 Tail Boom

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Abstract. Usually ultrasonic testing of complex aerospace components is carried out with squirter technique. However, water coupling delivers disadvantages like pressure variations, air-bubbles, limescales, algae and corrosion of the mechanics. Therefore a non-contact technique is preferable which avoids these disadvantages. The air-coupled ultrasonic technique large acoustical mismatch between air and solids can be reduced with special transducers in connection with special transmitter and receiver techniques. In spite of these optimisations the test frequencies have to be lower than 1 MHz. It has been already published that low ultrasonic frequencies are necessary for the inspection of CFRP sandwich components (even with water coupling). The air-coupled ultrasonic testing technique has been qualified for testing CFRP honeycomb sandwich structures. Because of the vertical alignment of the transducers on opposite sides of a complex component a ten axis robot scanning system is necessary. This paper presents first results and details of the automated air-coupled robot ultrasonic imaging system which is in operation by Eurocopter in Donauwörth since 2011. This project has been a co-operation between Eurocopter Deutschland, Robo-Technology, EADS Innovation Works, Ing. Büro Dr. Hillger, and Ostertag.

Introduction

Carbon fiber Composites are often used in aerospace applications because of their high specific stiffness and strength. Sandwich components with thin layers of GFRP and GFRP and a honeycomb core material are excellent materials for helicopter cells and tail booms. Their inspection after production requires a reliable non-destructive testing. Ultrasonic technique is the most used non-destructive inspection technique and provides the detection of delaminations, porosities debondings and others.

For the inspection of complex components usually the squirter technique is used. On opposite sides of the component a sender and a receiver are situated so that a through-transmission technique is applied. The coupling is carried out by water jets [1]. Air-coupled ultrasonic inspection (ACUI) avoids the disadvantages of coupling liquids like water corrosion, air-bubbles in the coupling path, algae in the water, problems with filter system for water, influence of force of gravity and others. However ACUI produces a large acoustic mismatch between the transducers and the test component so that a special system with adapted transducers is necessary. The Ingenieurbüro Dr. Hillger started the developments for aerospace components at the end of the 1990`s [2]. This paper describes the application of ACUI for a complex helicopter composite tail boom.

1. Air-coupled ultrasonic inspection

1.1 Testing Methods

The advantages of ACU are dearly paid by a large acoustic impedance mismatch between air for coupling and solids such as transducers and the test component. Using a standard ultrasonic equipment in the amplitude loss given by acoustical mismatches will be larger than 160 dB so that the received signal is covered form electrical noise [3]. Using water for coupling the loss will be lower than 40 dB which shows that water is a very good coupling media for composites. Additional the sound attenuation of the air has to be taken in account which is proportional to f (frequency)^4. In order to avoid addition signal damping the useful frequency range is situated below 1 MHz. Materials with a high sound damping such as sandwich components can only inspected with low frequencies in this range. Therefore ACUI even delivers advantages because of the smaller wavelength in the coupling medium (air in comparison with water) and the smaller sound beam diameter by the same test frequency.

1.2 Air-coupled Ultrasonic testing equipment

In order to reduce the large acoustical mismatch between the transducers and air a matching layer is used [4]. The layer with acoustical impedance between air and the active element of the transducer with a thickness of a quarter of a wavelength can reduce the amplitude loss from -90 to -40 dB! The disadvantage is the filter function of the matching layer which produces a relatively narrow band signal which is not useful for time of flight measurements. There are transducers with up to three matching layers which increase the bandwidth but the complex design is difficult to reproduce and decreases the degree of efficiency. Another possibility is the used of special ferroelectric foils which do not need matching layers because of their low acoustic impedance [5]. The high electrical impedance of this kind of transducers needs a high transmitter voltage (2.5 kV) and a special design of the internal construction. These transducers are currently in development. For a very robust inspection the AirTech transducer (Fig. 1) series have been developed [6]. These piezoelectric transducers with a matching layer provide a sensitivity of up to – 32dB which means a through-transmission receiver voltage in air without a component of 5V with an excitation of 200V. This excellent sensitivity enables a honeycomb sandwich inspection with a signal-to noise ratio of more than 20 dB in single shot technique.

Usually air-coupled ultrasonic testing is carried out in through-transmission technique with separate transmitter and receiver transducers on opposite side of the test component. There are also methods with a single sided access (pitch and catch arrangement). Usually a Lamb wave is generated in the component. The conversion from the transmitted longitudinal wave to guided waves is carried out by an angular incidence with same orientation of the transducers [7]. Because of the requirement of precise adjustment of the angels at all positions (also of large and curved components!) this method is limited to laboratory applications with flat components.

Fig. 1. AirTech 120 Transducers

Fig. 2. USPC 4000 AirTech

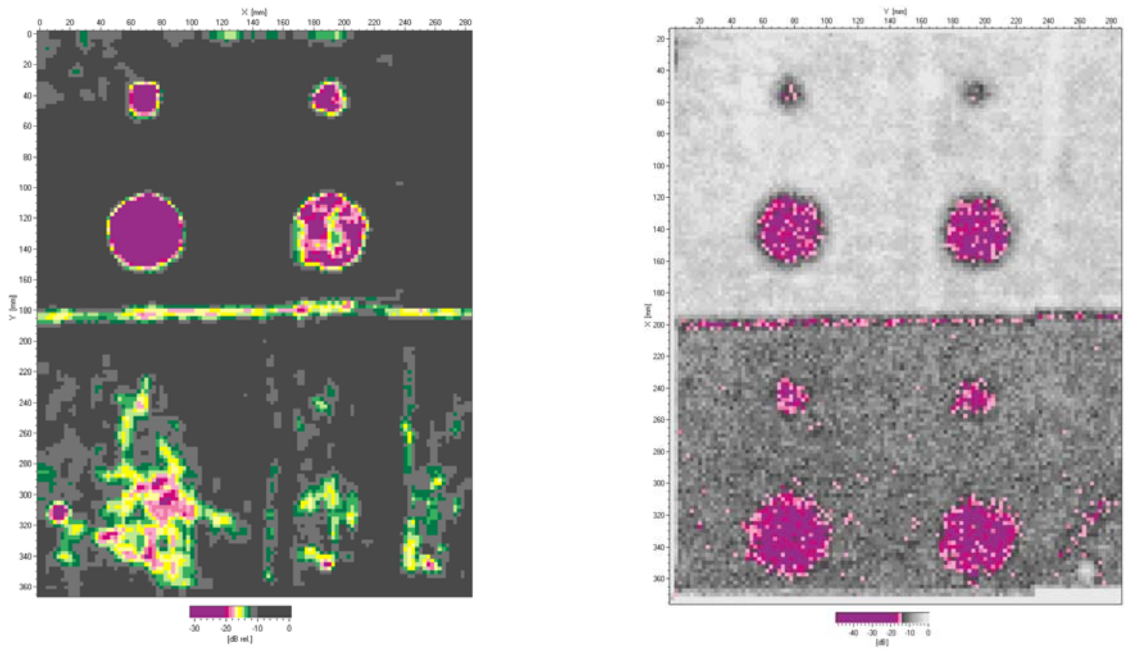
A powerful excitation of the air-coupled transducer is very important in order to get a high signal to noise ratio. Therefore the tone burst pulser AirTech 4100 has been developed which provides a quartz controlled frequency setting and the number of pulses. A multiple excitation (tone burst) of the transmitter with its centre frequency increases the acoustic power. An additional overload protection for the transducer is included.

On the receiver side an ultra-low amplification is required. Because of the receiver voltages in down to the 100 μV range a preamplifier is useful near to the receiving transducer. The short cable length from the receiving transducer avoids electromagnetic noise cross feed in the cable. Because of the pre-amplification the cable length to the USPC 4000 AirTech up to 50 m is uncritical.

Fig. 2 presents the USPC 4000 AirTech system in an industrial case with a computer for control and evaluation. The hardware and the software are of modular design so that additions for future application are easily possible. The hardware consists of the tone-burst transmitter AirTech 4100, the receiver Airtech 4032 and an analogue to digital converter. All other modules for amplitude and time-of flight measurements are software modules. The user interface is shown in Fig. 10. The software is easy to handle and provides real-time A-scan display, recording of C (amplitude) – and D (time of flight)-scans, as well as full-wave data recording. For the evaluation of the recorded data, the software Oculus provides the display with different pallets, contrast enhancement, digital filters, measurement functions and others.

1.3 C-scans of a sandwich component

Fig. 3 presents two C-scans of a honeycomb sandwich specimen with artificially inserted defects such as debondings in the skin. The C-scans are recorded with 800 kHz in echo-technique (water coupled) and with 120 kHz (transducer AirTech 120) with air-coupling. The C-scan recorded with air-coupled technique clearly indicates the defects. The reason for the darker background in the lower part of the C-scan is a larger thickness of the skins which deliver a higher sound attenuation. The water coupled echo technique better indicates the two defects on the top because of the smaller wavelength. On the other hand the defects near the back surface (lower part of the C-scans) are clearer displayed with air-coupled technique.



Echo technique with water-coupling | Through-transmission technique with air-coupling

Fig. 3. Ultrasonic C-scans of a sandwich test specimen with artificially inserted defects

2. Air-coupled ultrasonic system for the EC 145 Tail Boom

2.1 Requirements

A particular challenge for NDT testing is the novel design of the tail boom for the EC145 T2 (Fig. 4). The CFRP honeycomb sandwich structure is made integrally from a single piece described in [8]. The tail boom is a component of safety level 2 and has to be 100% inspected.

In order to avoid the disadvantages of water coupling it was decided to implement air-coupled ultrasonic testing for the inspection of this complex component (Fig. 5). The size are about 35 cm in diameter, 3 m length, the tube is not cylindrical but “egg-shaped”. This part consists of 80% honeycomb sandwich.

Fig. 4. Helicopter EC 145

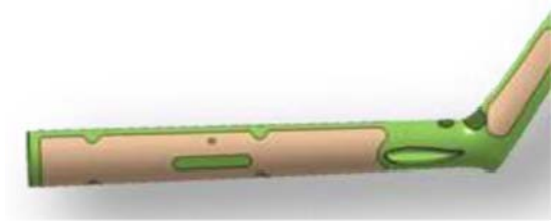


Fig. 5. Tail boom

One tail boom has to be inspected per week. The system has to scan the test areas fully automated. The automated evaluation of the data shall be in C-scans. Defects larger than 400 mm² have to be detected. The palettes have to be optimized for a clearly defect indication with a “necked eye”. A measurement of the defect size and a subsequent defect mapping are important.

To proof the ability of air-coupled ultrasonic technique and to support the design of such a system a pre-study was performed. Within this study the robustness concerning the misfit of the alignment of the probes was evaluated. This included variations in a distance between sample and probes, an offset shift, and a tilt (Fig. 6). With these arrangements C-scan images were recorded and compared with a reference scan. These results were used as a base to define the required positioning accuracy of such a system.

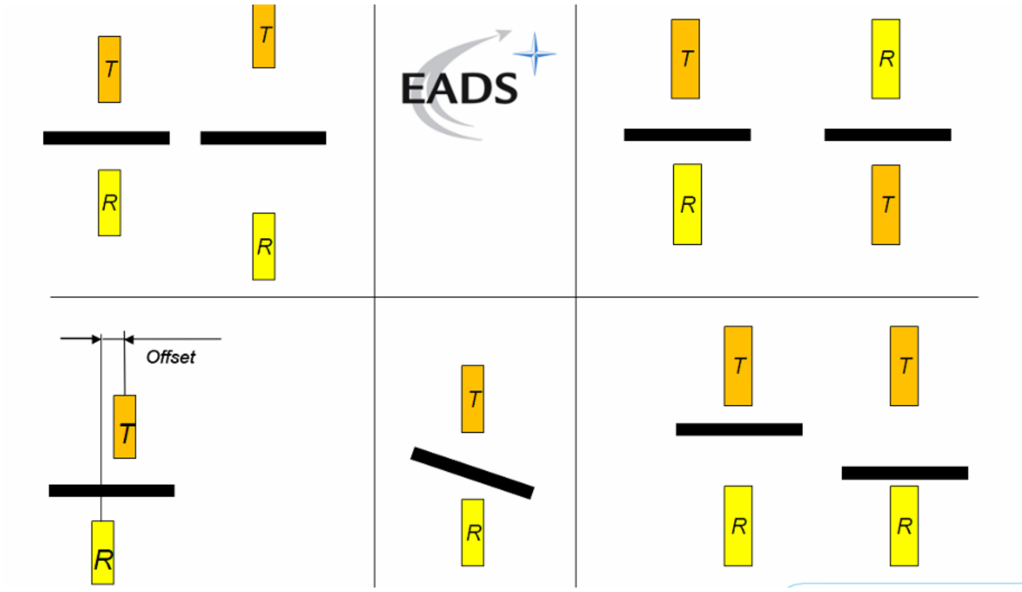


Fig. 6. Study concerning the misfit of the alignment of the probes, T: transmitter, R: receiver tranducer

2.2 Special scanning system

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 [1]. 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. Therefore a special scanning system had to be designed. This challenge was only possible with a co-operation between the companies Eurocopter Germany, Innovation Works, Robo-Technology, Ostertag and Ingenieurbüro Dr. Hillger [9].

Figs. 7 to 9 present an impression of the system for closed tubes. The size of the system is about 5,3 m x 4,9 m with a height of 10,6 m. The maximum cylindrical inspection volume is given by a length of 3000 mm and a diameter range from 300 to 1100 mm. The tail boom is inspected in vertical position. The mechanics consist of two CFRP-beams which are rotatable and adjustable in height each with a three axis pivot arm. The maximum inspection speed is 500mm/s. The maximum x-offset of the system +/- 1 mm. The programming of the track is carried out offline out of CATIA 3D component data.
The high level of positioning accuracy in dynamic motion has been proven using non contact three dimensional Laser positioning equipment.

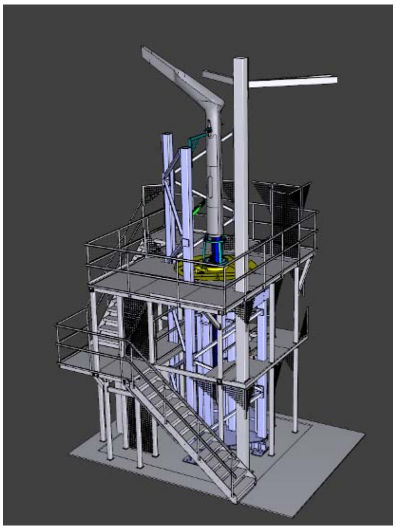


Fig. 7. Drawing of the air-coupled

Fig. 8. Photo of the facility

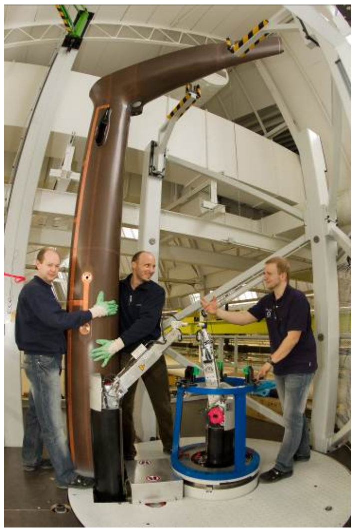


Fig. 9. Preparation of the tail boom inspection at the top platform

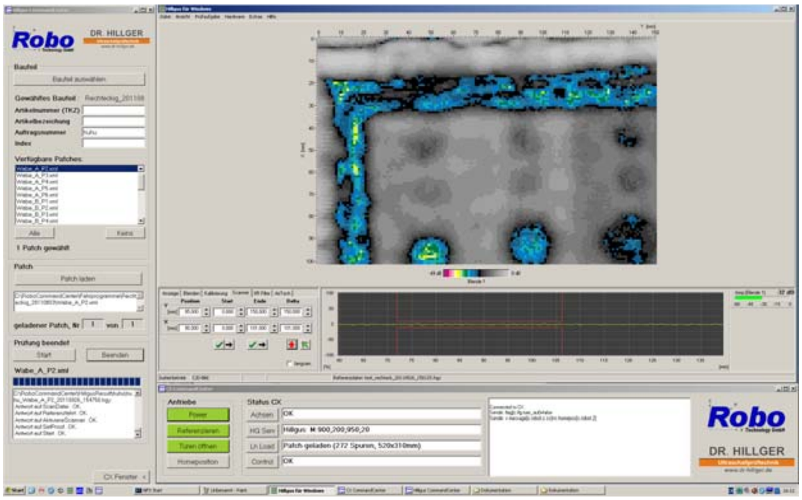


Fig. 10. User interface of the air-coupled ultrasonic system together with the scanner control

Fig. 10 shows the user interface of the air-coupled system in Donauwörth. This interface is a combination of the Hillgus for Windows software and the Robo-Technology control software of the 10 axis mechanics. This combination enables an easy handling of the inspection system. The displayed C-scan shows the result of a reference test block which is used for the control of the equipment.

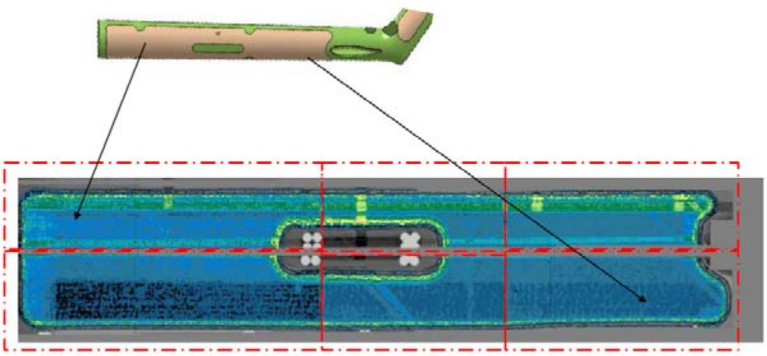


Fig. 11. C-scan of the tail boom

The C-scan in Fig. 11 is composed of different patches. It is clearly indicated that the received ultrasonic amplitude varies in dependence of complex construction. The dynamic range is high enough for inspection of the different areas with a constant gain setting. The C-scan do not show any defect in the tail boom. Before recording this scan the system has been calibrated with a reference component (see C-scan in Fig. 10).

Conclusions

The air-coupled ultrasonic inspection has been qualified for the inspection of the EC 145 T2 helicopter tail boom. In order to achieve a high reliability the standard through-transmission arrangement with AirTech 120 kHz transducers has been applied. The USPC 4000 AirTech ultrasonic system is combined with a ten axis mechanics. All relevant defects in the sandwich part of the tail boom can be detected. This challenge was only possible by a co-operation between the companies Eurocopter Germany, Innovation Works, Robo-Technology, Ostertag and Ingenieurbüro Dr. Hillger. The system is working since the end of 2011 and fulfils all requirements.

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