INSPECTION OF CFRP COMPONENTS BY ULTRASONIC IMAGING WITH AIR COUPLING

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Abstract

This paper reports on investigations of air coupled ultrasonic imaging techniques which are part of the German research project MaTech. Project partners are Airbus, Bremen, Ingenieurbüro Dr. Hillger, Braunschweig, and IntelligeNDT, Erlangen, with DLR, Braunschweig, as a subcontractor.

One task is the development of a modular ultrasonic imaging system which opens the possibility of basic research of air-coupled ultrasonic techniques for composites.

The development and construction of special transducers for air-coupling and the development of a system for echo technique are further research tasks of the MaTech project. This paper presents the features of the demonstrator III and first results from investigations of transducers and their application to composites.

Introduction

The air-coupled ultrasonic inspection is a very attractive method because it avoids the disadvantages of the coupling liquid (water, squirter-, immersion technique) or coupling paste [1]. However, the large impedance mismatch between solids and gas (air) produces an amplitude loss of more than 150 dB using through-transmission-technique with separate standard transducers as a transmitter and a receiver on opposite sides of a CFRP-component [2].

Therefore, a special equipment consisting of transducers with impedance-matching to air, a high-power pulser and an ultra-low noise preamplifier have to be used [3].

In order to obtain a high signal-to-noise ratio, resonant transducers are applied. Their low damping provides a high acoustic power output but a small bandwidth (about 10% of the centre frequency) .

Another method for increasing the signal to noise ratio is the application of narrow band filters in the receiver because the electronic noise is proportional to the square root of the bandwidth .

Narrow band transducers can produce resonances in the transmission coefficient. Fig. 1 shows the calculated λ/2-resonances in dependence of the thicknesses of CFRP-plates (sound velocity of 3100 m/s) in through-transmission technique using a test frequency of 350 kHz. It is shown that a thickness of 4.4 mm (λ/2) produces a 10 dB higher receiver amplitude than a 2 mm thickness. Because of the attenuation of 0,6 dB/mm the second resonance (2 λ/2) delivers only a maximum of 4.5 dB. These effects have to be observed by an inspection with narrow band pulses. It is possible that areas with delaminations produce higher through-transmission amplitudes than those without defects.

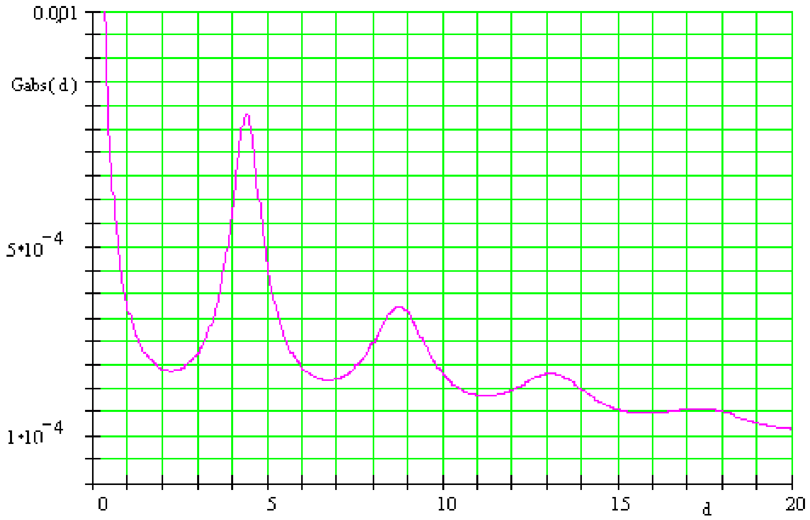


Figure 1. Resonances in the through-transmission coefficient in dependence of the thickness of CFRP-plates calculated for a test frequency of 350 kHz and an attenuation coefficient of 0,6 dB/mm

On the other hand, broadband air-coupled transducer are available; their smaller sensitivity can be compensated by pulse compression techniques [4].

There are several manufactures of air-coupled transducers. Usually the transducers are only used with the special equipment of the transducer manufacturer, so that it is difficult to compare their features and their technical data.

This paper reports on the aspect of „air-coupled ultrasonic technique“ of the German research project MaTech. It centres on the development of a fast imaging system (Demonstrator III), basic research, development of special transducers and on investigations of the detection of pores and delaminations in composites.

Development of the Demonstrator III

The demonstrator III provides basic research of air coupled ultrasonic technique and fast ultrasonic imaging. Fig. 1 shows the block diagram. The system is of modular design and enables different excitation pulses such as burst and free programmable signals. The special features are:

- transducers of different manufactures can be used, compared and evaluated;

- extremely fast amplitude measurement in order to use pulse repetition frequencies up to the physical borders;
- online evaluation of the RF-receiver signal (not of the video signal);
- single-shot technique, without averaging for high inspection speed;
- dynamic range of amplitude measurement up to 50 dB (single-shot);
- a quartz-controlled burst-transmitter with 1.2 kW output;
- an electrical impedance matching of the transmitter transducer in order to increase the acoustic power;
- a 12 bit ADC-board for A-scan digitising;
- full wave data recording;
- C-scan-software with evaluation functions, profiles and zoom;
- a free digital programmable transmitter in order to generate special pulses (such as "chirps" or coded signals);
- real-time A-scan-display ;
- RF-output, trigger in- and outputs;
- built-in computer with Windows NT operation system;

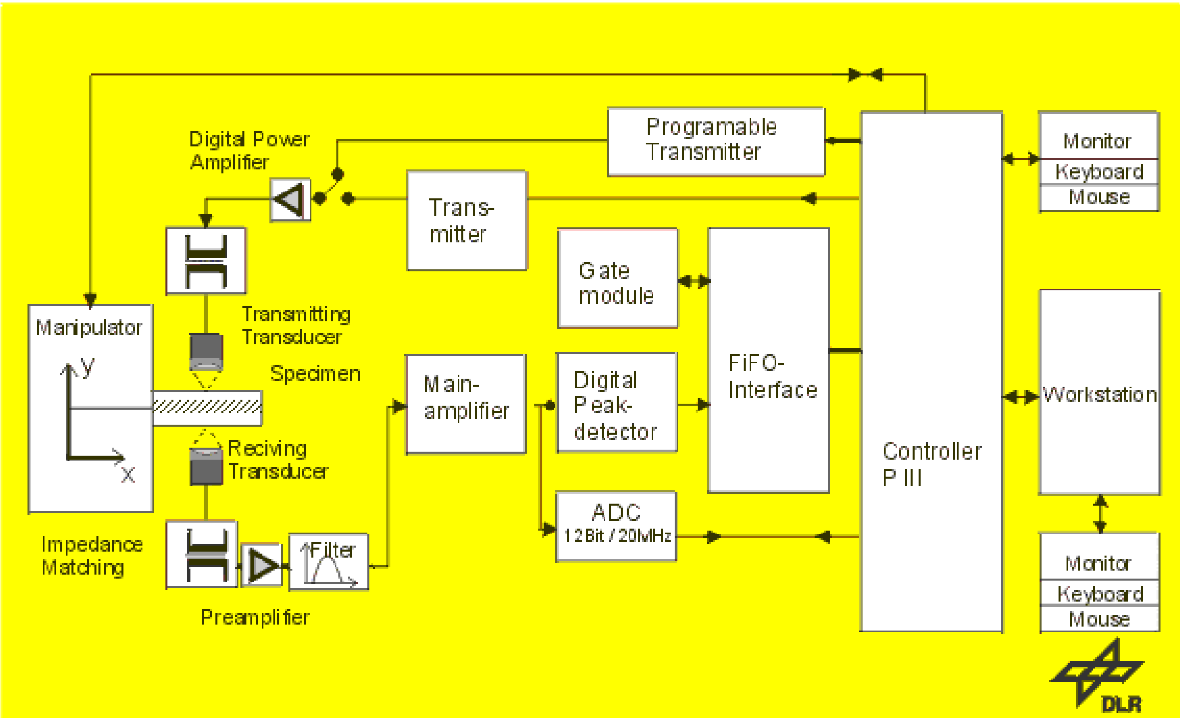


Figure 2. Block diagram of Demonstrator III

Investigations of air-coupled transducers

Transducers from different manufacturers have been investigated within the frequency range of < 120 kHz to 1 MHz.

The transducers have been characterised in through-transmission technique in air. The transmitting transducer was excited by a rectangular pulse of Us = 200 V. The output from the receiving transducer was directly measured by an oscilloscope. The sensitivity was calculated by

$$S\ (dB) = 20 \log (Ur/Us),$$

where Ur is the voltage of the receiving transducer.

For the measurement of the frequency range of the transducers a spike-pulser based on avalanche-transistors was used. This kind of pulser produces a very broadband excitation. The received, amplified and gated signal was given to a spectrum-analyser. Tab. 1 gives an overview of three different transducers.

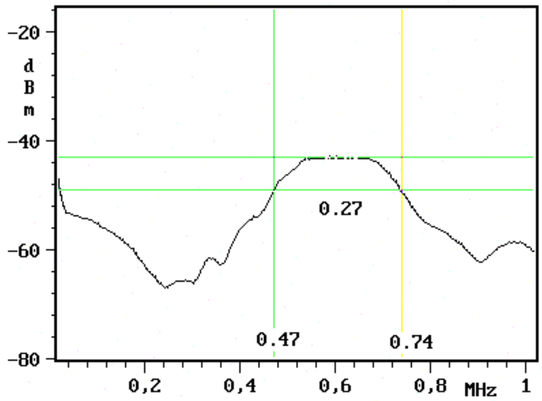
Transducer	Nominal frequency kHz	Active diameter mm	Frequenc y range kHz	Focus-distance mm	Beam-diameter mm	Focal Zone mm	Sensi-tivity
1	120	19,3	115-135	30	13	-	-32 dB
2	250	50	232-247	50	1,4	10,3	-43 dB
3	1 MHz	25	470-740	50	0,7	10,3	-62 dB

Table 1. Transducers for air-coupled ultrasonic technique

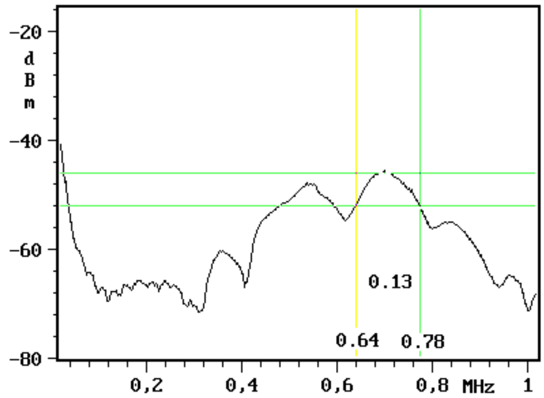
The highest sensitivity of -32 dB was measured with 120 kHz-transducers (transducer 1). This transducer is useful for the inspection of sandwich-components with foam-core (see chapter 4). Transducer 2 with an active diameter of 50 mm produces a very small sound beam calculated as 1.4 mm. Note that the wavelength in air is also 1.4 mm using a frequency of 240 kHz!
Transducer 3 provides a large frequency range of 470 kHz to 740 kHz, measured with a distance of 25 mm (Fig. 3, left hand side). If the distance between the transducer is varying, the frequency spectrum is changed, at a distance of 66 mm it is divided in two parts (Fig. 3, right hand side).

The results of the measured sound beam diameter are shown in Fig. 4. Two transducers of the same type were used for these measurements. One transducer was fixed, the other one was scanned in different distances around the centre. In different distances, C-scans were recorded. The echo dynamics of the C-scans with the smallest beam diameter are shown in

Fig. 4.

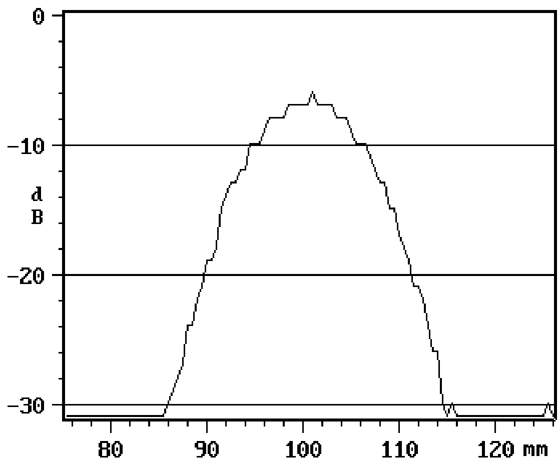


25 mm distance of transducers

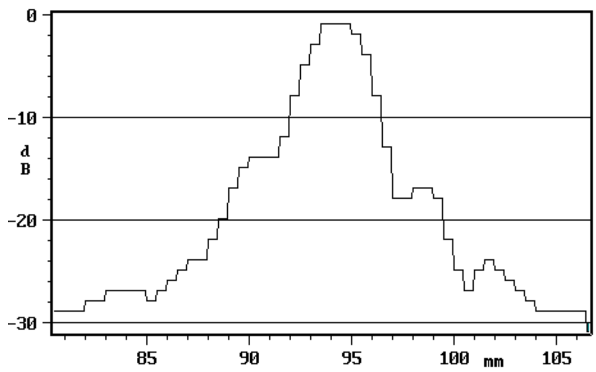


66 mm distance of transducers

Figure 3. Frequency spectra of transducer 3 measured in different distances



Transducer 1, 90 mm distance



Transducer 2, 90 mm distance

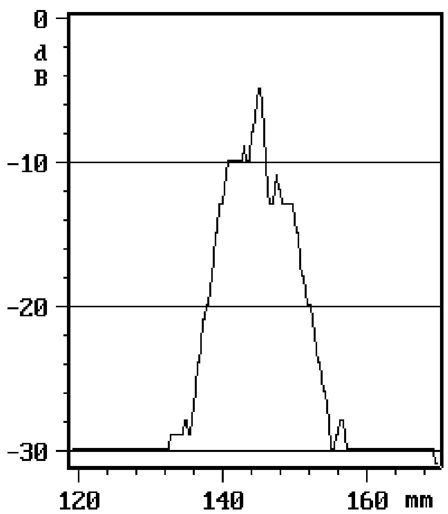


Figure 4. Profiles of the sound beams in focal distances of different transducers

Transducer 3, 95 mm distance

Application of air-coupled transducers

Air-coupled transducers were used for ultrasonic imaging of defects in composites. Because the demonstrator III is still in development, the HFUS 2400 AirTech was used for the investigations.
Sandwich components with cores of foam or Nomex can only be penetrated with frequencies in a range of 50 to 800 kHz. Because of these low frequencies the ultrasonic wavelength is relatively large and reduces the resolution. Inspections are usually accomplished in through-transmission technique with separate transmitting and receiving transducers on opposite sides of the component (coupling with water, Squirter technique).

Fig. 5 shows a complex component with foam core and skins of CFRP. The component is stringer stiffened and was impacted with energies of 10 to 30 Joule at different positions (directly on the stringers and between two stringers). Therefore the sizes of the defects are quite different. The C-scan recorded in through-transmission technique with air-coupling (two transducers type 1) clearly shows the positions of the stringers with an amplitude of 0 dB, the areas with foam between the skins (-9 dB) and defect areas with amplitudes of - 22 to -24 dB.

Fig. 6 presents a C-scan of a sandwich with Nomex-cores and skins of CFRP. Two transducers 2 are used. The small beam diameter enables a clear presentation of the cores and of the defects. The echo dynamic curve clearly presents the different amplitude ranges for different areas: CFRP without cores deliver 0 dB , - 2 to –25 dB can be measured for defect-free areas with cores and –31 dB for damaged areas with cores.

Summary

This paper treats of ultrasonic investigations with air coupling which are part of the German research project MaTech.

Subtasks are: development and construction of an ultrasonic imaging system ("Demonstrator III") including special transducers, basic research of transducers, investigations of application to composites, and further developments of the potential of the echo-technique.

The demonstrator is under construction and will have the following features:

- application of transducers of different manufactures;
- fast scanning with a single-shot data acquisition (without signal averaging);
- C- scans and full-wave-scans with 12bit resolution;
- transmitter with a peak-power of 1.2 kW;
- different pulse for excitations: rectangle, burst, chirp- and coded signals;
- true Windows™ software.

Fist investigations showed that :

- air-coupled techniques provide a better resolution for sandwich-components than water-coupled ultrasonic techniques;
- a low bandwidth can produce $\lambda/2$-resonances in through-transmission technique;
- broadband transducers have about a 20 to 30 dB lower sensitivity, which require methods like chirp signals for increasing the signal to noise ratio.

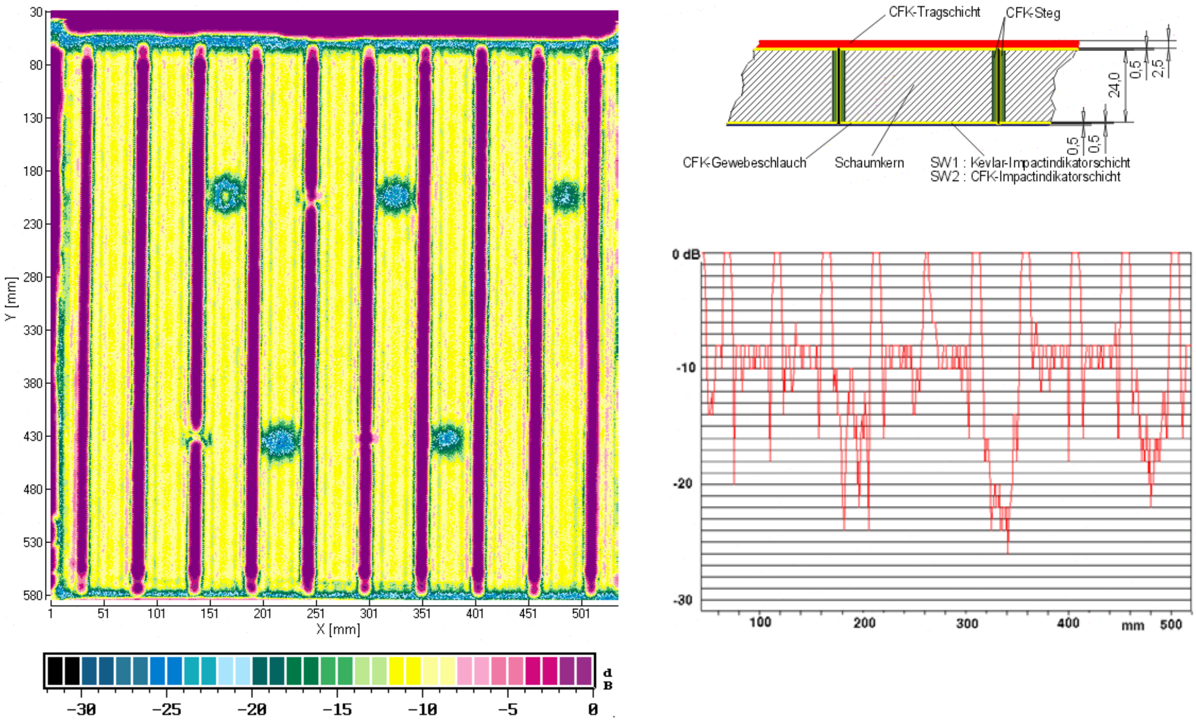


Figure 5. Sandwich component with foam core, C-scan, construction (cross-section), and echo-dynamic curve

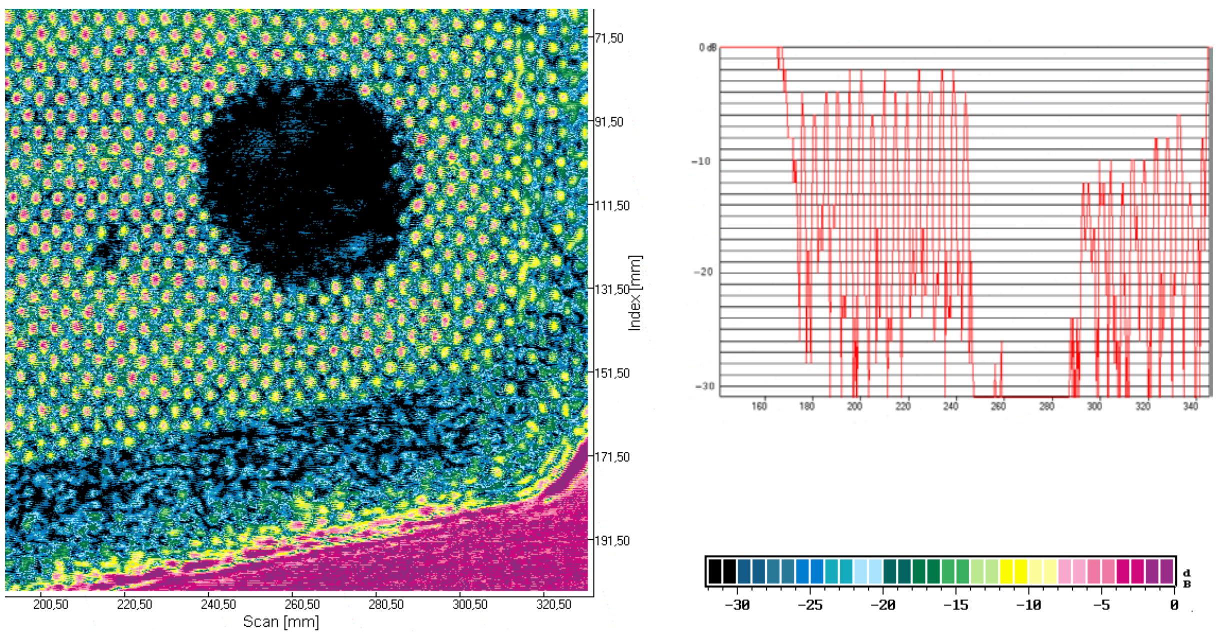


Figure 6. C-Scan and echo-dynamic curve of a CFRP- fabric sandwich component with Nomex-cores (thickness of 21 mm)

Further investigations with free-programmable transmitter signals, signal analysis and multi-element transducers will be carried out for the application of echo-technique.

References

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