Visualisation of Guided Wave Propagation by Ultrasonic Imaging Methods

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Abstract - Composite materials are more and more used for primary structures in aerospace components. Examples are the new aeroplanes Boeing 787 and the Airbus A350 which are mostly produced out of composites.
In order to take advantage of the specific properties of composites the complexity of the structures increases more and more. On the other hand the costs for inspection after fabrication and especially in service have to decrease. Cost effective NDT-methods have to be implemented.
This paper presents the possibilities of guided waves inspection techniques for complex composite components. Guided waves such as Lamb waves can be easily excited and received by applied piezo-elements and penetrate large areas so that complex structures in principle can be inspected (SHM). However, for each frequency in minimum two different wave modes exist so that the responses are difficult to evaluate. The Lamb wave research is carried out within the EU project AISHA. The ultrasonic imaging technique is successfully used for the visualisation of the Lamb wave propagation. This combination between SHM and ultrasonic technique provides the optimisation of the sensor and actuator placement and also an interesting method for in-field inspection of air aerospace components. The coupling of the scanning receiver transducer can be carried out with water split coupling as well as with air (non contact).

Keywords: Structural Health Monitoring (SHM), Lamb waves, visualisation of wave propagation, ultrasonic imaging techniques

1 Introduction

Carbon fibre reinforced composites (CFRP) provide high specific stiffness and strength. In order to take advantage of the specific properties, the complexity of the aircraft structures increases more and more [1]. On the other hand, costs and time-consumption for in-service inspection need to be decreased. Therefore cost effective Non-Destructive Testing (NDT) methods have to be developed. A well established NDT-method is the ultrasonic imaging technique, which is able to detect internal defects with a high degree of resolution and reliability [2]. However, this punctual measurement technique requires time consuming scanning of the whole area to inspect. Modern complex composite structures (e.g. sandwiches, double shell fuselage) pose further strong restrictions on the accessibility for conventional ultrasonic testing. Lamb wave can penetrate large areas of components and therefore are able to provide fast in-service inspections without time consuming scanning [3, 4, 5, 6]. There are passive and active methods. During occurrence of a damage Lamb waves are generated, which can be received by PZT transducers [7] (acoustic emission technique). In the active method, Lamb waves are excited and received at distinct positions. Piezo patches at fixed positions of the structure are often used as actuators and as sensors [8]. These patches can be embedded in the component or attached to the surface. In opposite to longitudinal waves used for ultrasonic imaging techniques, at a certain frequency at least two Lamb wave modes with different phase velocities exist: a symmetric and an asymmetric one. Usually, Lamb wave propagation is highly dispersive. The received signals are a complex mixture from different modes and therefore difficult to evaluate. Research topics at DLR are visualisation of the Lamb wave propagation and the interaction between damages and signal correlations between progressing damage types and active Lamb wave signals.

2 Visualisation of Lamb Wave Propagation

2.1 Principle

In order to get more information about the propagation of Lamb waves in components and their interaction with defects it is very helpful to visualize the wave propagation. Usually this is done by a laser interferometer which is able to monitor the out-of-plane surface deformation [10]. At DLR, the ultrasonic imaging technique for composites has

been successfully used and further developed. Therefore this technique is used for the visualisation of the Lamb wave propagation and their interaction with defects, too.
Fig. 1 describes the combination between ultrasonic imaging and Lamb wave testing which is carried out at DLR. All ultrasonic methods like phased array-, echo- and air-coupled ultrasonic technique deliver volume data sets from full-wave data recordings and also the Lamb wave method described later. All data can be processed by our software and after signal processing there is the option of imaging, animation and evaluation by signal analysis.
For the visualisation of the Lamb wave fields and their interaction with defects, one actuator at a fixed position on the bottom of the specimen has been used as a transmitter (Fig. 2). The excitation is carried out by the rectangle burst generator. Because of the harmonics a software-filter on the receiver side is used which provides a narrow band signal. A second PZT-patch is coupled by water film to the surface and moved by an XY- scanner in a meander track. Because of the water coupling, Lamb waves are received only with low amplitude. Therefore an ultra-low noise preamplifier and a band pass filter are necessary. These analogue signal procession, additional data conversion, timing and scanner control are carried out by the USPC 5000. At each point of the scanning grid, a full-wave Lamb wave A-scan is recorded. Out of the 3D-data files several presentations can be calculated and presented [11]:

- 2D Amplitude images, showing the maximal amplitude during a selected gate [t_1, t_2] (C-Scan).
- 2D time-of-flight image within a certain gate [t_1, t_2] (“D-Scan”).
- The Lamb wave A-scan at any recorded position together with spectral analysis.
- Slices [x, t], [y, t] similar to B-Scans in conventional ultrasonic technique
- Video-animations showing the wave propagation.

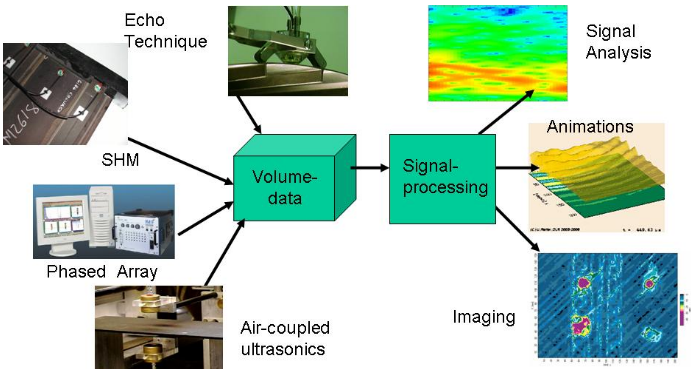


Figure 1: Network of different NDT-methods

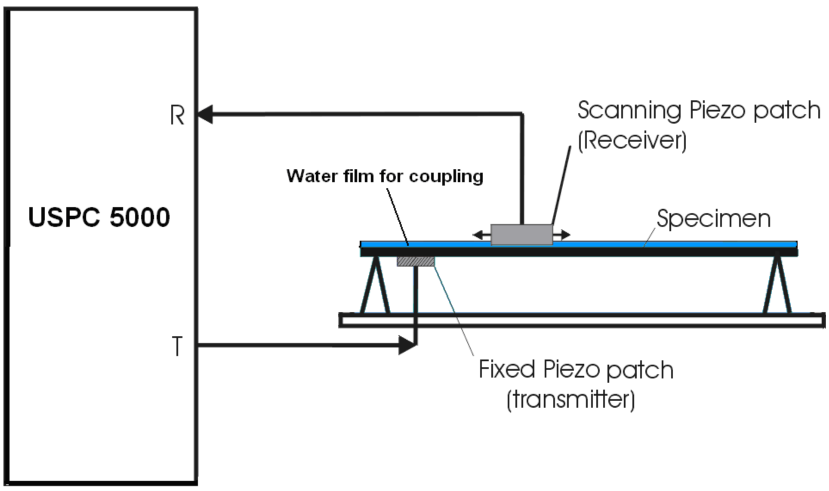


Figure 2: Experimental arrangement for visualisation of Lamb wave propagation

2.2 Results of Panel 22

Figure 3 shows on the right hand side a photo of the 850x605 mm large CFRP-panel with four stringers and applied piezo patches. The ultrasonic D-scan (time of flight C-scan) on the left hand side clearly indicates the stringers and a debonding of the 2nd stringer (caused by an impact). The seven positions of the transmitter patches (T1-T7) as well as those of the receivers (R1-R7) are drawn-in.

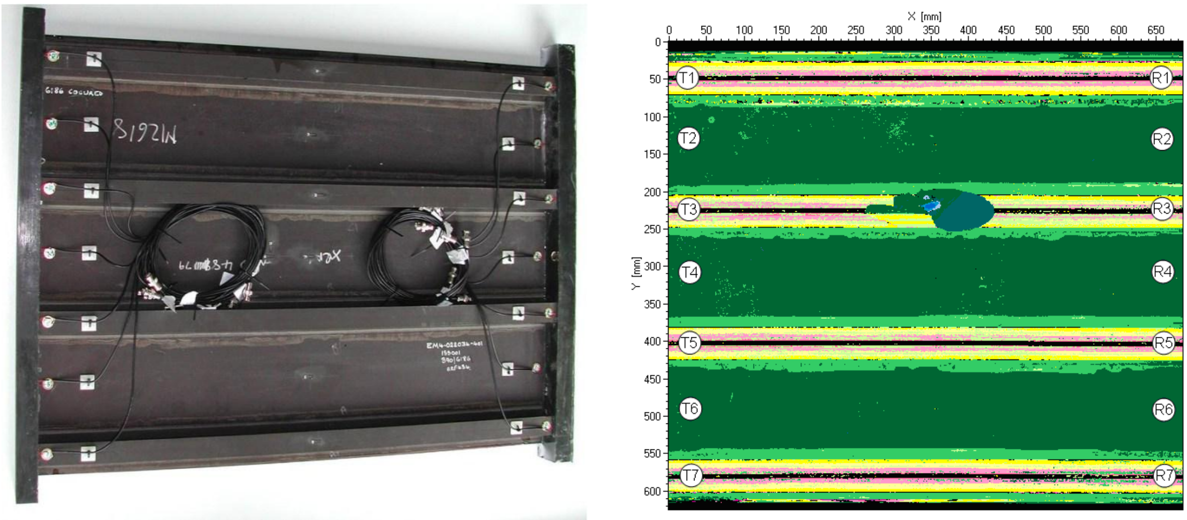
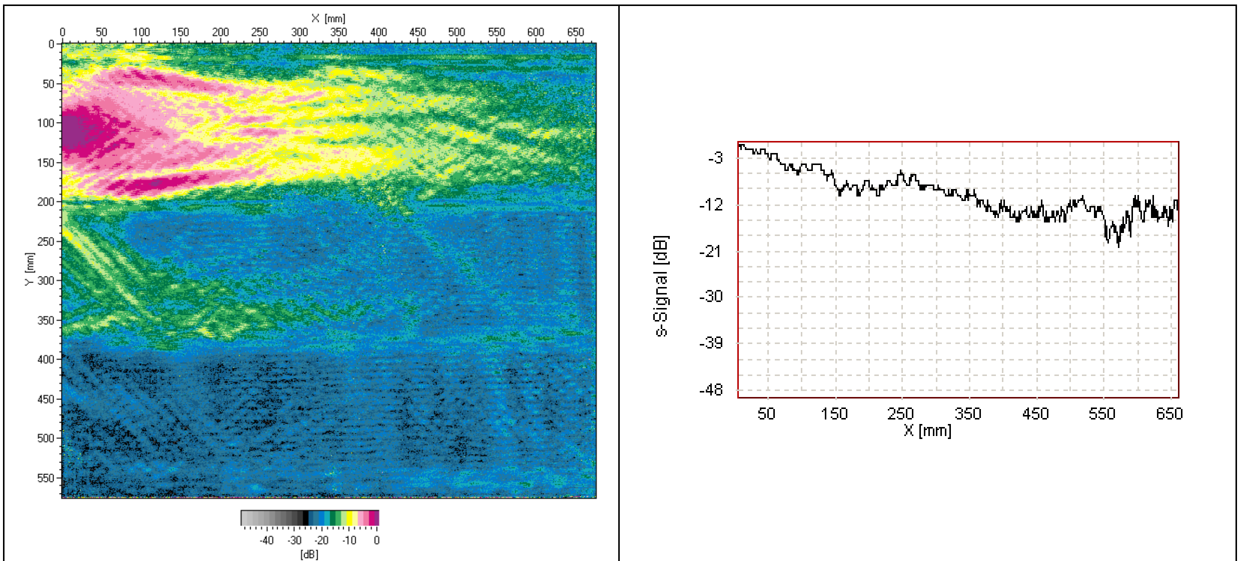


Figure 3: Stringer stiffened CFRP-panel 22, left hand side: photo, showing also the clamping at the edges, right hand side: ultrasonic D-scan with drawn-in positions of the piezo patches

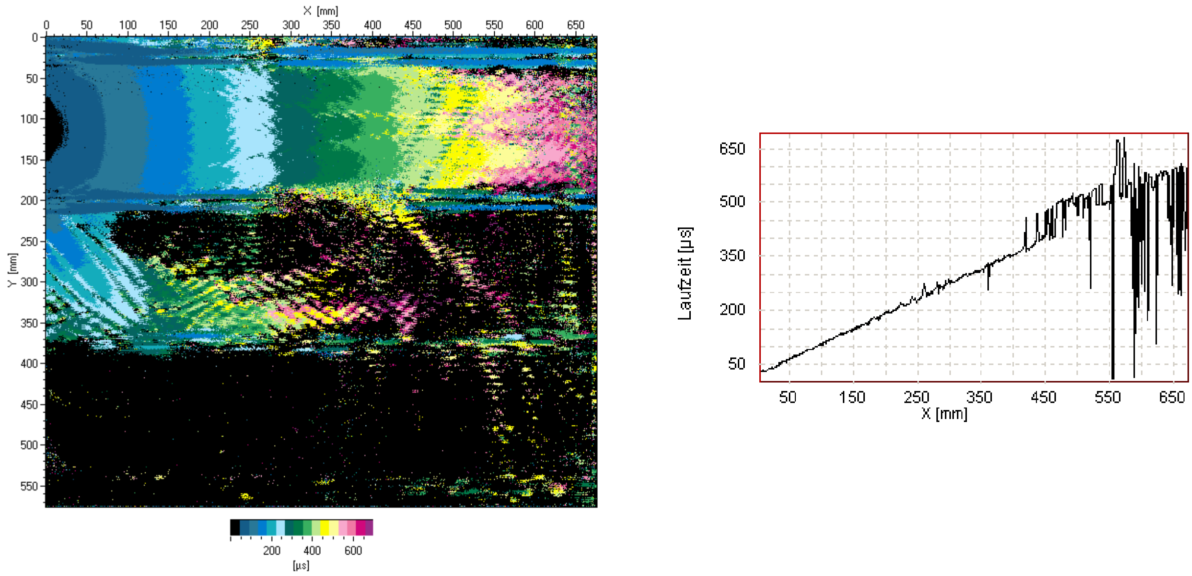
Figure 3 shows on the right hand side a photo of the 850x605 mm large CFRP-panel with a thickness of 2.5 mm and four stringers. At each edge there are seven applied piezo patches. The ultrasonic D-scan (time of flight C-scan) on the left hand side recorded with a 10 MHz transducer clearly indicates the stringers and a debonding of the 2nd stringer (caused by an impact). The seven positions of the transmitter patches (T1-T7) as well as those of the receivers (R1-R7) are drawn-in.



Lamb wave C-scan recorded with excitation of T2	Echo-dynamic curve (horizontal)

Figure 4: C-scan of Lamb wave propagation and echo-dynamic curve recorded with excitation of actuator T2

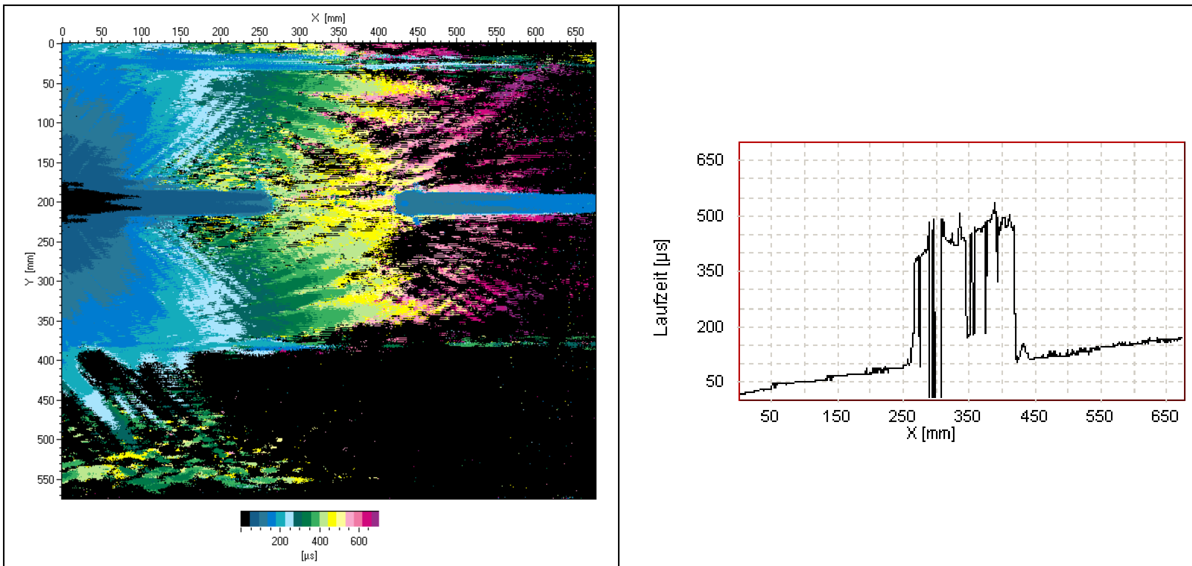
Figure 4 presents a C-scan recorded with excitation of actuator T2 and a horizontal echo-dynamic curve at y=100. The excitation of T2 situated in the field between stringer one (on the top of the panel) and two delivers Lamb wave propagation mainly in this area. The two stringers form a guide for Lamb waves. The amplitude measured by the echo-dynamic curve is influenced by reflections from the stringers. The amplitude only decreases from 0 to – 15 dB within a distance of 820 mm which verifies the Lamb wave propagation over large distances. The change in thickness of the component in the region of the stringers is the reason for the "wave-guide" effect. For a Lamb wave inspection of stringer stiffened component it is necessary to place sensors and actuators in each field which is separated by stringers. The "cross-talk" on the right hand side between stringer two and three is produced by the clamping (see Figure 3). Another one can be observed at the position (x, y) = (400,200) where a stringer debonding is situated.



Lamb wave D-scan recorded with excitation of T2 | Time of flight curve (horizontal)

Figure 5: C-scan of Lamb-wave propagation and time of flight curve recorded with excitation of actuator T2

Figure 5 presents a D-scan (time of flight C-scan) recorded by an excitation of T2 which also shows the wave propagation between the stringers one and two. Also the cross-talks on the left hand side and at the position of the stringer debonding are visible. Additional to the C-scan the calculation of the gradient of the time of flight curve delivers the phase velocity of the Lamb wave. It was calculated to 1,300 m/s.



Lamb wave D-scan recorded with excitation of T3	Time of flight curve (horizontal)

Figure 6: D-scan and time of flight curve using T3 as an actuator

Figure 6 presents a D-scan received by excitation of actuator T3 and a time of flight Using T3 which is situated on the stringer two as an actuator, the wave propagation is mainly on the stringer indicated by the smallest time of flight (marked in blue in the D-scan). The stringer debonding is clearly indicated yellow and green colours (larger time of flight). The time of flight curve shows a large increase at the position of the stringer debonding. The calculated velocity of the Lamb wave propagated on the stringer is 1000 m/s, different from those ones which are only propagated in the skin.

3 Conclusions

Lamb wave testing promised to get a low cost and fast inspection of complex components because of their large-area propagation and interaction with defects. However, the evaluation of the received Lamb wave signals is very difficult due to the generation of at least two modes at one frequency, the non-directional propagation of the Lamb waves, reflections from all edges and the complex interaction with defects in components. The visualisation of the wave propagation provides a better understanding of these complex interrelationships and enables the optimisation of a Lamb wave system for the detection of defects in components. The ultrasonic imaging technique is practicable for this challenge, especially with full wave data recording. The 3D-data files of Lamb wave fields provide the calculation of C- and D-scans as well as the calculation of video-animations which impressively show the propagation.
The air-coupled ultrasonic imaging technique is very attractive for inspections because it avoids the disadvantages of the coupling techniques. However, special transducers and a special signal processing are required. This non-contact-method does not influence the Lamb wave propagation by the coupling liquid of a receiver transducer.

References

[1] H. Wilmes, B. Koslesnikov, A. Fink, C. Kindervater, New design concepts for a CFRP fuselage, Conference CFRP for future aircraft fuselage structures, 24th October 2002, DLR Institute of Structural Mechanics, Braunschweig, Germany, proceedings on CR-ROM
[2] Hillger, W.: Ultrasonic imaging of internal defects in CFPRP-Components, 6th European Conference on Non Destructive Testing. Conference Proc. part 1, (1994) pp. 449-453 00
[3] Toyama and J. Takatsubo, Lamb wave method for quick inspection of impact-induced delamination in composite laminates, Composites Science and Technology 64-13
[4] K. K. Diamanti, J. M. Hodgkinson, C. Soutis, Detection of Low Velocity Impact Damage Using Lamb Waves GARTEUR meeting at Imperial College, London, 16th September 2002
[5] Joseph L. Rose, A Baseline and Vision of Ultrasonic Guided Wave Inspection Potential, Sweden. Report 2001-25
[6] Paget, C. A. Active Health Monitoring of Aerospace Composite Structures by Embedded Piezoceramic Transducers, Department of Aeronautics, Royal Institute of Technology in Stockholm,
[7] F.-K. Chang, J. F.C. Markmiller, A New Look in Design of Intelligent Structures with SHM, Proceedings of the 3rd European Workshop on Structural Health Monitoring 2006, pp. 5-2
[8] Valdez S.H.D. and C. Soutis. Health Monitoring of Composites using Lamb Waves generated by Piezoelectric Devices. Plastics, Rubber and Composites¸v.29, 2000, 475-481.Journal of Pressure Vessel Technology, August 2002, Vol. 124
[9] www.Dr-Hillger.de
[10] B. Köhler, M. Kehlenbach, R. Bilgram, Optical Measurement and Visualization of Transient Ultrasonic Wave Fields, Acoustical Imaging, Vol. 27, Edited by W. Arnold and S. Hirsekorn, Kluwer Academic/Plenum Publishers, Dordrecht & New York, 2004, pp.315-322
[11]W. Hillger, U. Pfeiffer. 2006. Structural Health Monitoring Using Lamb Waves, 9th European Conference on Non-Destructive Testing, Berlin, published on CD.