ULTRASONIC IMPACT DETECTION TECHNIQUES FOR AN EC135 TAILBOOM

A. Szewieczek[1], W. Hillger, D. Schmidt, M. Sinapius
[1]artur.szewieczek@dlr.de, DLR (Germany)

ABSTRACT

Sandwich components with honeycomb cores and composite skins out of CFRP or GFRP afford lightweight designs with high specific stiffness and strength. They exhibit high potentials for special structures in aerospace. On the other hand these materials are impact sensitive and show a high complexity at non destructive testing or structural health monitoring methods.

Within the EU project AISHA II (Aircraft integrated structural health assessment) investigations on a 3.5m long EC135 Tailboom were carried out at the German Aerospace Center (DLR) with the purpose of evaluating and adjusting established ultrasonic testing methods on the specific structure and the development of a qualified SHM (Structural Health Monitoring) system.

In ultrasonic echo-technique only frequencies below 1 MHz penetrate the curved structure. Therefore a low frequency technique with one side access was adjusted for in-field inspections. The harmonics of the transmitter excitation and the scattering of the material are suppressed on the receiver side by filters. This technique provides clear results. C-Scans of the structure allow the identification of any relevant structure damage. However, a disadvantage is the time consuming scanning and the following costs for service inspections.

SHM with Guided waves affords an alternative for damage detection in service. Guided waves like Lamb waves propagate over wide ranges with low attenuation and interact with impacts. They can by excited by PZT transducers. Lamb waves are dispersive and show an anisotropic propagation in the Tailboom structure. On low frequencies there are two wave modes. The symmetric S_0 and the asymmetric A_0 with different wavelengths interact together and with their reflections and refractions. Beyond that mode conversions are possible. The evaluation of single sensor signals poses a challenge.

The visualisation of Lamb wave propagation provides a better understanding of wave behaviour in the structure. Therefore, an adjusted ultrasonic scanning technique was used. An air coupled sensor is moved over the component. For every scanning point a full A-Scan is stored in a special data file. Out of this different types of visualisation can be calculated (A-, B-, C- and D-scans and video animations of wave propagation). A further task for network design is the calculation of virtual sensors. A sensor layout and position can be used for calculating its expected signal. This technique enables the optimisation of entire sensor networks.

This paper presents results of different ultrasonic inspection techniques for the EC135 Tailboom. A pulse-echo scanning technique is used as reference for impact visualisation. A SHM system based on Lamb waves has been developed. Impact detection resolution and fidelity are presented.

1. INTRODUCTION

Within the EU project AISHA II (Aircraft integrated structural health assessment) a Tailboom of an EC135 helicopter was investigated [1, 2]. The purpose was the identification of a suitable realization for a Structure Health Monitoring (SHM) system with Lamb waves and its demonstration in a first implementation.

Lamb waves propagate in plates and plate-like structures over wide distances with low attenuation and interact with impacts and stiffness discontinuities [3, 4]. They can be excited and received easily with PZT transducers. In principle, they can be used for impact detection. However, the wave propagation is very complex. Different modes exist (symmetric and asymmetric). On high frequencies higher order wave modes accrue. Every mode is dispersive. The interaction with defects consists out of reflections, refractions and mode conversions. Sensor signals are very hard to evaluate without additional information.

Figure 1: EC135 Tailboom

The curved 3.5 meter sandwich structure of the Tailboom (see Figure 1) consist out of a honey comb core, CFRP and GFRP skin layers with different thickness and an inserted lightning protection. Such complex components are very different from simple laboratory examples. A calculation of wave propagation of Lamb waves is very hard to realize, particularly in case of unknown material parameters. Extensive investigations are necessary for the identification of usable Lamb wave mode(s) and frequencies for damage detection.

2. ULTRASONIC IMAGING TECHNIQUE

Air coupled ultrasonic testing of the Tailboom in impulse echo technique is usable as reference method for impact detection [5]. Figures 2 and 3 show a C-Scan and a FFT-Scan of an impacted Tailboom section. The FFT Scan shows the maximal frequency for each scanning point. An impact situated at the position x = 540 mm and y = 130 mm is easy identifiable. A separation of the honeycomb core is visible at the position x = 1000 mm.

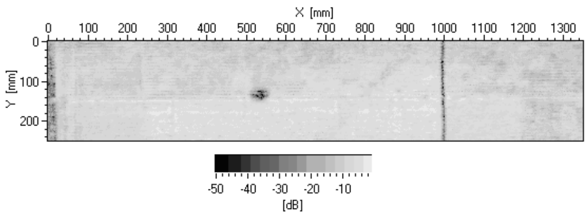

Figure 2: Echo technique C-Scan

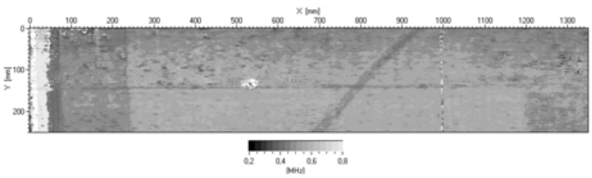

Figure 3: FFT-Scan

3. AIR COUPLED SCANNING TECHNIQUE FOR SHM

An air coupled scanning technique for Lamb wave investigations was developed at the DLR in order to visualize and analyse wave propagation in complex structures.

In this technique, a PZT glued on the specimen is used for Lamb wave excitation. An air coupled sensor is moved over the specimen surface with a constant gap and delivers entire A-scans for every scanning point. All data is stored in a special data file.

Out of this files different kinds of visualization, like A,- B,- C,- D-scans, video animations of wave propagation etc. can be calculated. Furthermore special algorithms allow a detailed analysis of the wave propagation and interaction with complex structure conditions and defects [6].

4. DEVELOPMENT OF A SHM SYSTEM

Investigations show that only frequencies below 30 kHz penetrate the entire Tailboom thickness and enable guided waves for impact detection. Waves with higher frequencies propagate only in the skin layers. Furthermore it is known, that impacted sandwich structures can show a small and barely visible delamination in the skin and a larger one in the core [7]. As a result waves with higher frequencies are not useful for impact detection because of the small interaction with the skin delamination and no interaction with the core.

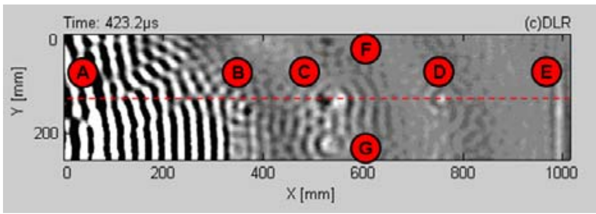

Figure 4: Snapshot of wave propagation in the Tailboom

Figure 4 shows a Lamb wave propagation snapshot in the Tailboom captured with air coupled ultrasonic technique. The actuator is marked with (A). The honeycomb core separation identified in Figure 2 is indicated with (E). At (C) an interaction with an impact can be observed. PZT sensors were glued on the Positions (B), (D), (F) and (G). Their influence on the wave propagation can be observed, too.

Figure 5 illustrates a B-Scan acquired along the red line in Figure 4. The actuator on position (A) excites a fast S_0 mode with low amplitude and 4000 m/s (185mm wavelength) and a slower A_0 mode with 550 m/s (25 mm wavelength). On Positions of the glued PZT's (B and D), the impact (C) and also at the core bonding (E) mode conversions from S_0 to A_0 can be identified. In opposition to the conversion at the PZT's, a phase shift between positive and negative propagation direction is visible at the center position of the rest mode conversions.

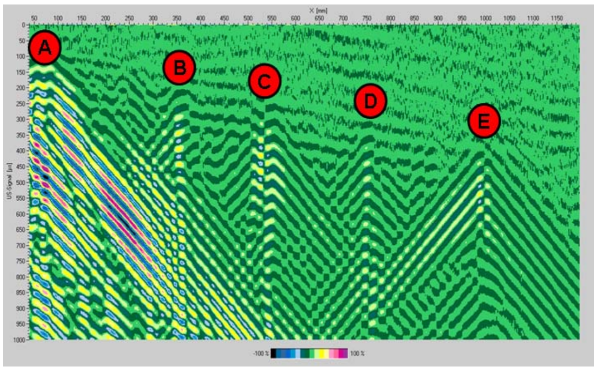

Figure 5: B-Scan along red line in Fig. 4

Because of the influence of glued PZT's on the wave propagation an air coupled sensor network was used. Therefore, selected electret microphone capsules with a build-in amplifier are arranged in arrays of eight sensors. Foam carriers are used here for a low-impedance acoustic coupling to the inner Tailboom skin (Figure 6). In an earlier implementation each sensor array was mounted on a continuous carrier. Waves propagating through the carrier caused crosstalk between different sensors. Because of this a separate carrier is necessary for each sensor. Eight sensors are grouped

to a logical array and are connected to a multiplexer. Eight sensor arrays are combined by a global multiplexer. This enables signal acquisition from all 64 sensors through one coax cable.
Actuators are positioned in areas of identified core separations in order to minimize mode conversions by the separations. Because of the curved Tailboom skin, DuraAct [8] actuators are necessary (Figure 6, left side). A multiplexer is used for activation.

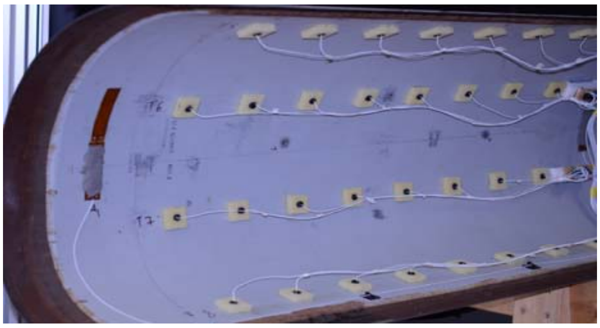

Figure 6: Implementation of SHM sensor network for the Tailboom

An interface box was designed in order to connect the SHM network to the data acquisition system USPC5000 [5]. It allows ultrasonic inspections by an integrated scanner controller as well as data acquisition from discrete sensor networks. The system stores acquired signals in the same data format as the ultrasonic scanning system. This allows data processing and analysis of different measurements by same software without separate alignment.

Figure 7: Data acquisition system USPC5000.

The implemented sensor network is optimized for an impact detection based on mode conversions on impacts. Because of the high out-of-plane amplitude of the A_0 mode converted signal components are easy measurable. On the other hand neither used actuator positions nor the air coupled sensors cause additional mode conversions.

Additional software was written for data analysis and impact detection. After input of component and sensor network layout any measurement data file can be linked with the internal sensor database. This allows a quick configuration of the software for new components or sensor networks independent from used measurement equipment.
The acquired sensor signals can be analysed in different ways and can be compared with a baseline, which enables the indication of a significant signal difference between different structure conditions (before and after an impact) or basic conditions (e.g. different temperatures).

Impact investigations were executed at our project partner Aeronautical Technologies Centre (CTA) in Spain. Their analysis confirms the impact detection ability of the implemented SHM system:

Figure 7 illustrates the sensor network layout drawn out of sensor positions and Tailboom parameters by our analysis software. A 15 Joule impact was inserted near by the sensors S3.6 and S3.7.

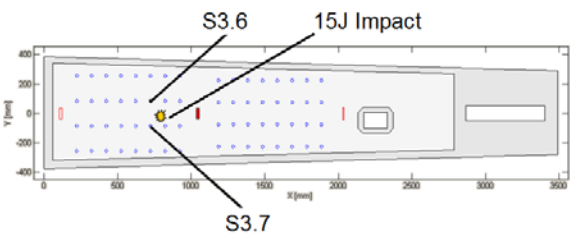

Figure 7: Sensor Network Layout

Figure 8 shows the corresponding sensor signals before and after impacting and the signal difference between both structure conditions. An new signal component caused by the impact can by observed in both plots between 300 and 500 microseconds after excitation (red mark).

The optimal time range for possible impact detection can be calculated out of B-scans of wave propagation for every sensor and enable an implementation of automatic detection algorithms.

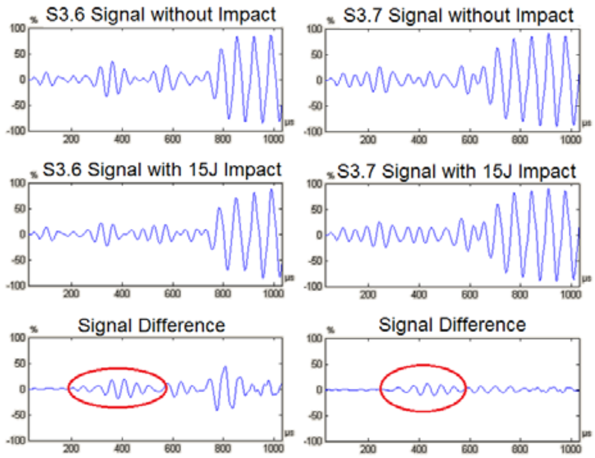

Figure 8: Sensor signals before and after impacting with 15 Joule nearby sensors 3.6 and 3.7.

The addition amplitude in the difference signal of sensor S3.6 between 600 and 900 microseconds after excitation is cause by a phase shift of the signal after impacting. Such effects can be identified by enhanced signal analysis. A challenge for an automatic impact detection algorithm can be the consideration of such phase shifts additional to amplitude analysis.

5. CONCLUSION AND OUTLOOK

It was shown, that complex sandwich structures like the EC135 Tailboom can be monitored by SHM systems in principle.

A consideration of wave propagation in such components is necessary and poses a hard challenge for the design of entire SHM systems.

The visualisation of wave propagation based on air coupled scanning technique allows a better understanding of wave behaviour in any complex structure and is a helpful tool for sensor network development.

Analysis software allows an identification and localisation of impacts by manual examination. Enhanced algorithms shall be developed for automatic impact detection and localisation in future implementations.

ACKNOWLEDGEMENT

The investigations have been supported by the European Commission (EU project AISHA2: Aircraft integrated structural health assessment, contract no. EU-FP-CP 212912). The authors would like to thank the European Commission and all partners for their support.

REFERENCES

[1] www.aisha2.eu

[2] W. Hillger, A. Szewieczek: "Advanced NDT-Techniques for Damage Detection in a Honeycomb Composite Helicopter Tailboom", Open Project Meeting AISHA II, Leuven, Belgium, 28th October 2011

[3] Lamb, H. "On Waves in an Elastic Plate." Proc. Roy. Soc. London, Ser. A 93, 114–128, 1917.

[4] Jan Achenbach. 1987. “Wave Propagation in Elastic Solids (North-Holland Series in Applied Mathematics and Mechanics),” ISBN-13: 978-0720403251, Elsevier Science, November 1987.

[5] Ultrasonic systems see: www.dr-hillger.de

[6] A. Szewieczek, W. Hillger, “Analysis of 3D-Acousto Ultrasonics Data Files,” Proceedings of the 7th International Workshop on Structural Health Monitoring 2009, Stanford University, Stanford, CA, September 9 - 11, 2009

[7] M. Gädke, J. Baaran, H.-C. Goetting, R. Rolfes (2001) Impact Behavior and Residual Strength of Sandwich Structural Elements Under Static and Fatigue Loading. In: 42nd AIAA/ASME/ASCE/AHS/ASC,Structures, Structural Dynamics, and Materials Conference and Exhibit, Seattle, Washington, 16.-19. April 2001 . ISBN 1-46347-499-9.

[8] P. Wierach: “Elektromechanisches Funktionsmodul” (Electro-mechanical functional module), German Patent DE 10051784 C1, August 2002.